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MINISTRY OF PENSIONS

ARTIFICIAL LIMBS AND THEIR RELATION TO AMPUTATIONS

LONDON
HIS MAJESTY'S STATIONERY OFFICE
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HANDBOOK ON ARTIFICIAL LIMBS AND THEIR RELATION TO AMPUTATIONS

FOREWORD

It has been my intention, as it was that of my predecessors, Mr. H. Ramsbotham, Mr. R. S. Hudson and Major Tryon, to make known, for the benefit of medical and surgical practice in this country, some of the results of the Ministry's experience in the handling of certain of the more important disabilities that were caused by the Great War. Owing to the large scale of casualties, our experience has been exceptionally wide.

A large proportion of the work of the Ministry of Pensions has been devoted to the care of those who suffered amputation of limbs as the result of war injuries and to the provision for them of suitable artificial limbs. The number requiring such care was so large, and the problems involved so novel, that the experience of the Ministry's Medical Officers has far exceeded that of any other medical body in the country. The Ministry has thus perforce become a pioneer in the development of the modern surgery of amputations, in the construction of all types of artificial limbs and appliances and, what is of almost equal importance, the fitting of the artificial limb under trained surgical supervision.

Many requests for information on these subjects have from time to time been made to the Ministry by surgeons and others, and general lectures and demonstrations have been given at the Ministry's Limb-Fitting Centre at Roehampton by Dr. R. D. L. Kelham, and, on artificial arms, by Captain A. R. Maxwell. These have been largely attended, and requests have been made that their substance should be made generally available.

This handbook, the preparation of which was initiated by Dr. J. H. Hebb, prior to his present service with the Ministry of Health, has accordingly been compiled on the basis of the lecture notes. It is so arranged that reference can easily be made to particular details of amputations, or specifications for artificial limbs, but it does not profess to be a complete textbook, or to give a full description of all amputation stumps and artificial limbs, and its arrangement has necessitated some repetition. It is, however, my earnest hope that the handbook, which I trust will be followed by similar handbooks on other classes of disability, may prove to be of service.

WALTER WOMERSLEY,
Minister of Pensions.

August, 1939.

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HISTORICAL INTRODUCTION

Prior to the Great War the supply in this country of artificial limbs, whether for soldiers, sailors, or civilians, had been a comparatively small matter, and such organisations as existed for the purpose were therefore not very numerous or extensive, nor were the limbs supplied always satisfactory. These conditions continued to prevail in the early months of the war, and while in some cases it was found practicable for men who had undergone amputation in a military hospital to be retained in the institution until they had been fitted with an artificial limb, the pressure on hospital accommodation was in general such that a great number of amputation cases had to be discharged, the patient being required to attend subsequently at the limb-maker's business premises to get measured for a limb which, when ready, was sent to him at his home. Under this arrangement misfits were fairly common and, in the absence of any efficient machinery for effecting alterations and adjustments, and for training a man in the use of his limb, it frequently occurred that the man discarded the limb and reverted to the use of crutches. In face of the ever-growing number of amputation cases it was clear that this state of affairs could not be allowed to continue, and that both the selection and fitting of the limb, and the training of the man in its use, must be carried out under the personal supervision of a competent surgeon.

The first step taken in this direction was the formation, in 1915, of the great pioneer institution for limb-fitting at Roehampton. This was followed by the establishment of other limb-fitting centres, associated with military or other hospitals, at Edenhall, Musselburgh; Erskine House, Glasgow; Duke of Connaught Hospital, Bray, Ireland; Ulster Volunteer Hospital, Belfast; and the Prince of Wales's Hospital, Cardiff. Men who had undergone amputation in the various Service hospitals were transferred to these centres when their stumps were soundly healed. When the stump had become sufficiently strong to enable weight and pressure to be borne, the centre proceeded with the supply of a provisional or temporary limb. By this means the man was enabled to discard crutches, and the fact that it had thus become possible for him to get about in a more active way and to use his arms in educational work greatly improved his mental outlook on the future.

The adoption of the principle that the type of limb should in each case be prescribed by a competent surgeon and that he should supervise the case until the limb had been fitted and accepted as satisfactory, revealed even more fully than had previously been apprehended how inadequate were the resources and experience of British limb-makers for the production of limbs to the extent required. It was known that in the United States of America, with its larger number of accidents, the artificial-limb industry had been developed on wider and more comprehensive lines than in this country. Types of legs manufactured by American firms were, therefore, examined by the surgeons at Roehampton, and this led to the selection of two of these firms for the supply of artificial limbs required at that centre. They established workshops at Roehampton, where they manufactured limbs that included materials and parts imported from America. For some time these two firms furnished the majority of the legs and a small number of arms, although supplies continued to be obtained from British firms to the extent of their capacity. A third American firm obtained permission to appoint an

agent at Roehampton for the supply of a particular type of artificial arm, under an arrangement that involved manufacture in America from a plaster cast of the stump and measurements taken by the agent at Roehampton. The main supply of arms, however, continued to be obtained from British firms.

So far there had been no attempt at standardisation of patterns, but in June, 1916, the Army Council appointed an Advisory Committee, composed mainly of surgeons and engineers, under the chairmanship of the Hon. Sir Charles Parsons, K.C.B., F.R.S., to consider the question of the best forms of artificial limbs, and the possibility of some measure of standardisation in order to facilitate their supply and subsequent repair. One of the main functions of this Committee was to initiate and watch experiments in the construction of artificial limbs with a view to improving them in every way possible, in order to ensure that disabled men got the very best substitutes that could be produced for the limbs that they had lost. The work of this Committee took considerable time, during which it was found that disadvantages continued to arise from the diverse character of the artificial limbs supplied. While the number of types, even for similar amputations, was very considerable, the difference of pattern was in many instances relatively small, and the variation did not in all cases offer an appreciable advantage. A markedly adverse effect of this diversity of types and patterns was that the smallest differences were sufficient to interfere seriously with the speedy and satisfactory carrying out of repairs and renewals, because of the difficulties experienced by the limb makers in repairing or renewing limbs made by other makers. So much was this the case that it often became necessary for the limbless man to be sent back to the original maker for the purposes of limb repair, which involved unnecessary hardship and inconvenience to the man and possibly the loss of his employment. The Committee addressed themselves closely to this aspect of the matter and formed the opinion that a careful selection of the best parts of various patterns would afford the nearest approach to perfection in the construction of an artificial limb, and they proceeded with measures for the standardisation of limbs on this basis. The result of the Committee's work in this direction was greatly to reduce the number of types of limbs supplied, and thereby to simplify and speed up very considerably the work of effecting repairs and adjustments.

In consequence of the increasing casualties resulting from the extended operations of the British Army during 1917, the number of amputation cases came to exceed the accommodation available at the existing Limb-fitting Centres. To meet the situation, the accommodation at Roehampton was increased, and, in addition, sections of Military Hospitals at Liverpool, Manchester, Leeds, and Birmingham were set aside. Further provision was made in London at the Charterhouse and Paddington Military Hospitals, while workshops for repairs were also opened at Putney, Park Lane, and Queen's Gate.

Early in 1917 the Ministry of Pensions was established and thereupon the responsibility for the provision of artificial limbs for disabled soldiers and sailors devolved on the Minister. In September of that year the Ministry contemplated the establishment of a workshop for research and experimental work in connection with artificial limbs and appliances. As, however, it was learned that it had for some time been the practice of limb-makers to send their artificial limbs and appliances to the Inventions Department of the Ministry of Munitions for testing and advice, the Ministry approached that Department on the matter. In the result, it

was agreed between the two Ministries that the object which the Ministry of Pensions had in view should be secured by setting-up in the Ministry of Munitions Inventions Department a completely equipped experimental workshop for the testing, improvement of design and workmanship, and reduction of cost of artificial limbs and appliances. This experimental workshop was established in May, 1918, at Imber Court, Thames Ditton, and was conducted in close co-operation with the surgical and technical advisers of the Ministry of Pensions. Although very useful work was done in the experimental workshop, it soon became evident that serious disadvantages resulted from the fact that it was not under the control of the Department responsible for the supply and fitting of artificial limbs. This matter was investigated by a Departmental Committee, under the Chairmanship of Mr. Herbert Guedalla, and the Committee, in their report of the 20th May, 1919, recommended that the workshop should be transferred to the Ministry of Pensions. This recommendation was carried into effect early in 1920, when the workshop was transferred to Roehampton Hospital. It continued to do very useful work until November, 1924, when its purpose having been achieved it was closed down.

The task of providing a permanent artificial limb for each one of the cases who had suffered amputation continued to tax the resources of the Ministry up to about the end of 1919, but many months before this task had been accomplished it had been realised that it would be necessary to provide a duplicate limb, as and when it might become practicable to do so, in order that the man should not be prevented from following his employment, or be otherwise restricted in his activities, while the first limb was undergoing adjustment, repair, or renewal. It became possible to make a start with the supply of duplicate limbs in January, 1920, but it was not until April, 1923, that the task was completed. Experience showed that the policy of supplying limbs in duplicate was thoroughly justified, and although, as might be expected, a few pensioners allowed both limbs to get out of repair, the great majority showed their appreciation of the convenience and advantage of being in possession of a spare limb by promptly bringing to notice any need that might arise for adjustment or repair of either limb.

Early in 1920 the duties connected with the supply and adjustment, repair and renewal of artificial limbs were delegated by Ministry Headquarters to the Regional Offices that had been established in 1919 in the principal cities throughout the country. There were then in active operation 18 Limb-fitting Centres, the character of which had somewhat changed in the process of time since their opening. By reason of the technical improvement in limbs, the increased capacity of contractors to supply new limbs and to effect repairs, and the greater knowledge, skill, and experience of surgeons in the selection of a limb suitable for the individual case and the actual fitting of it, the number of instances in which it was necessary to retain the man at the Centre from the time of his first attendance until his case had been finally completed was greatly diminished. Moreover, cases attending for first supply who would therefore need to be retained for exercise in the use of their limb were now much fewer in number. The Centres had thus become more in the nature of depots than hospitals, although they were still associated with Orthopædic Hospitals or Clinics where surgical advice and treatment for the amputation stump were available if required.

Standard-pattern wooden legs were introduced by the Ministry in 1921, and proved very satisfactory, especially for below-knee amputations;

while at the same time they rendered the work of repair and replacement of parts much simpler and more expeditious. At that time the number of metal limbs which had been supplied by the Ministry was very small. Such as had been supplied were made of a light metal —" duralumin "— by a London firm of limb-makers who had been making metal limbs for some years. Other manufacturers were now engaged in exploring the possibilities of metal construction of limbs, and it soon appeared that duralumin might be found to be superior to wood as the material for limbs, because very light limbs could be constructed from this material without sacrificing strength or security. The Minister therefore appointed a Committee in July, 1921, under the Chairmanship of the Right Hon. Sir Archibald Williamson, Bart., P.C., M.P., " to enquire into the arrangements for the supply and repair of the various types of artificial limbs which are provided under the Royal Warrants and Orders in Council; and into the comparative advantages of the metal limb and the wooden limb; and to make recommendations thereon."

The evidence given to the Committee showed that there was little or no reason for dissatisfaction in regard to the artificial arms being supplied, and that in effect the question for investigation resolved itself into the suitability of the artificial limbs supplied by the Ministry for cases of leg amputation above the knee. There were in all some 41,000 cases of amputation (including approximately 2,000 officers) of which 11,600 were arm cases and 29,400 leg cases, and of these latter the number of above-knee amputations was approximately 17,000. The Committee found that as compared with the very heavy wooden legs that had been supplied during the war, the later types showed a continuous succession of improvements, and they noted that the standard-pattern wooden legs recently designed by the Ministry, with the assistance of the trade, embodied the latest improvements in lightness and mechanical efficiency. The Committee also commended the scientific work carried out at the Ministry's experimental and testing department at Roehampton in connection with the manufacture and use of " Certalmid " for artificial limbs, and in the development of light metal limbs. A definite recommendation in favour of the issue of metal legs was made by the Committee, in addition to the continued issue of the standard-pattern wooden leg. In pursuance of this recommendation metal above-knee legs were issued by the Ministry more and more extensively as the sources of supply were increased. For cases of amputation below the knee, however, the Ministry's standard light wooden limb was usually supplied, although a metal limb was issued if it was certified to be preferable for surgical reasons.

Improvements continued to be effected in the designs of metal legs, and as a knowledge of the superiority of the metal over the wooden limb was spread amongst pensioners, difficulty began to be experienced in satisfying the demands for it. The number of firms from which supplies were obtained was increased, until in 1925 there were no less than 14 firms supplying orders from the Ministry. A position was thus brought about similar to that which had arisen in the case of wooden legs before standardisation was effected, for although the metal legs were of only two main types they differed in details of construction, and there was again difficulty and delay in the execution of adjustments and repairs. This unsatisfactory condition of things was aggravated by another cause. In January, 1923, a scheme had been introduced under which the makers of artificial legs undertook to maintain the legs supplied by them in good repair for a prescribed period from the date of issue, in consideration of

payment by the Ministry of a specified maintenance fee. The scheme was not applied to artificial arms as the number of these was relatively small. Not only did the maintenance scheme save a great deal of accounting work in respect of a multiplicity of small and detailed accounts for repair work, but, what was of much greater importance, it afforded a valuable guarantee to the Ministry that the best workmanship and material were employed in the manufacture of the limb. After some time the contracting firms refused to continue with the maintenance scheme, and this fact, coupled with the difficulties already mentioned in connection with the supply of metal legs, led to the appointment by the Minister in April, 1925, of a further Committee, under the Chairmanship of Sir Godfrey Collins, K.B.E., C.M.G., M.P., " To inquire into the present arrangements for the supply and maintenance of metal limbs which are provided under the Royal Warrants and Orders in Council, with special reference to the question as to whether the needs of the limbless pensioners would be met if the issue were limited to one or two of the types of limbs at present supplied; and to make recommendations thereon."

The information given to the Committee showed that two-thirds of the supply of metal legs was in fact being carried out by two firms, and that their products were most favoured by both pensioners and surgeons. The Committee recommended that the Ministry's sources of supply should be confined to these two firms, and the Ministry accordingly entered into contracts with them which not only yielded a reduction in prices but secured maintenance and repair on satisfactory terms. Moreover, under these two contracts, the limb-makers, in view of the termination of all other contracts for the supply of metal legs, were made responsible not only for the maintenance, good repair and fit of the artificial legs supplied by themselves, but also, in certain cases, of those which had been supplied by other firms, the principle adopted being the payment of a flat-rate monthly maintenance fee per leg. The supply of the Ministry's standard-pattern wooden leg continued to be obtained under a contract which included the maintenance clause, and in respect of these legs, and also the metal legs, the Ministry safeguarded themselves from the possibility that, under the influence of the maintenance obligation, the maker's desire to produce a thoroughly sound limb might lead to limbs being somewhat increased in weight. No appreciable increase in weight was permitted, even though it became necessary to increase the weight of certain joints in order to get a sufficient margin of safety against breakages, and to make other changes in the construction of wooden and metal legs.

By these arrangements the best interests of the pensioner had been secured at a diminished cost to the State. In carrying the new arrangement into effect the convenience of disabled men was most carefully considered. Freedom of choice (subject of course to surgical requirements) on the part of the pensioner as between the two selected types of metal legs was in no way interfered with; and, as far as possible, steps were taken to meet the reasonable views of pensioners in regard to modifications in detail of the selected legs, or even the supply of special legs in exceptional cases. At the same time, however, the Ministry took special care to ensure that there was no renewal of a limb unless the limb previously in wear had become unsuitable or beyond economic repair.

As time went on it became possible, as it had been previously with the wooden limb, to produce an improved metal limb incorporating the best features of a number of different types, and at this stage, in 1934,

arrangements were made for the supply of all-metal limbs to be obtained from one firm of limb-makers only. It was thus rendered practicable to effect a further measure of standardisation and to bring into use special mechanism devised by these limb-makers in collaboration with the officers of the Ministry. This step proved so satisfactory that in 1935 the Ministry had no hesitation in deciding to obtain its wooden as well as its other limbs from the same source, and to apply to the wooden limbs improvements which had recently been designed and adopted for metal limbs.

In regard to the policy of standardisation of limbs which has been steadily pursued by the Ministry, supported by the advice of the various Departmental Committees which at different times have investigated the matter of limbs-supply, it should, perhaps, be made clear that while standardisation involves uniformity in many of the individual parts of the limbs, such as joints, the actual details of fitting and control permit of sufficient variation to ensure the most suitable and most comfortable adjustment of the limb to the needs of the individual pensioner. Standardisation within this degree of necessary variation has unquestionably resulted in the Ministry's being able to supply the best limb yet procurable in this country or elsewhere. Nevertheless, research and experimental work are still being continued with a view to effecting even further improvements. Largely as a result of standardisation it has for some years been practicable for certain mechanical repairs to be effected without its being necessary for the pensioner to attend at a limb-fitting centre. In consequence an efficient system has been developed for the transmission of limbs by post, rail, etc., for repair and return, and this procedure has been of considerable benefit to pensioners in obviating the loss of time that personal attendance at a limb-fitting centre would occasion. At the present time upwards of 50 per cent. of the repairs required are satisfactorily dealt-with in this way.

It has already been stated that the number of officers and men who suffered amputation during the period of the Great War (4th August, 1914, to 31st August, 1921) and were supplied with artificial legs or arms, was approximately 41,000. Subsequent cases of primary amputation in respect of injuries or disease due to Great-War service brought the total number of limbless officers and men who had been supplied with artificial limbs to a figure slightly exceeding 42,000. Owing to reduction by deaths, however, the number of pensioners for whose artificial limbs the Ministry has been responsible at any one time probably never exceeded 40,000, and by 1938 the number had fallen to approximately 34,700.

The total number of artificial legs supplied by the Ministry up to 1938 was about 142,600 and the total number of artificial arms about 31,600. Supply of new limbs continues at the rate of more than 4,000 annually.

In addition to its work for amputees of the Great War, the Ministry's organisation has been called upon to do most of the work of supply and fitting of artificial limbs and appliances for the Admiralty, War Office, and Air Ministry, and the fitting of artificial limbs for a number of local authorities, including the London County Council. More recently, under arrangements made by the Committee of Roehampton Hospital, other civil cases throughout the country can be dealt with by the Ministry's surgical staff.

On an average about 850 cases, other than those arising from the Great War, are dealt-with annually by the Ministry.

PART I—LOWER EXTREMITIES

1. THE IDEAL STUMP FOR ABOVE-KNEE AMPUTATIONS

The ideal stump should be able to control and use an artificial limb without undue tiredness, discomfort, or pain, and to withstand, without damage, the stress and strain of wearing it. Such a stump is the result of a combination of factors, of which length is not necessarily the most important, and its characteristics are best appreciated by an exact knowledge of the stresses and strains that the stump may have to endure. The dynamics of limb-wearing, however, have been so fully described and illustrated by Muirhead Little* that a repetition of the detail there supplied is unnecessary, and it will be sufficient if the functions of the stump are indicated here in general terms.

When the patient wearing the artificial limb is standing erect his weight is carried mainly upon the skin and tissues covering the ischial tuberosity. Some weight is also borne by the gluteus maximus, and a very slight amount by the skin and tissues of the upper and outer aspect of the stump, just beneath the great trochanter, but this portion of the stump cannot take much pressure as the femur lies near its surface.

In order to take a pace forward with the artificial leg the stump must be flexed sufficiently to lift the whole leg forward and, also, to overcome any friction in the artificial knee piece so that the leg may flex at the knee. On completion of this forward pace the artificial foot touches the ground, and, as it does so, the stump must be extended forcibly and braced against the posterior surface of the socket, so that the artificial knee is extended and held in that position. This muscular action prevents the knee from shooting forward suddenly and the patient from falling when he again applies his weight to the limb in the vertical position. Whilst these movements are being carried out, and also whilst a patient is standing "at ease," the opposing forces of the adductor and abductor muscles of the stump must be evenly balanced. In the process of walking with an artificial leg the stump does not remain in a constant relation to the socket; there is an up and down movement of the stump (piston action), the amount of "rise" of the stump from the socket varying from a half to one inch. With each step the patient takes, this piston action produces an alternate tension and relaxation of the soft tissues over the end of the stump as well as some friction on the skin of the stump, especially in the upper part. The stump must, therefore, be of sufficient muscular power and of sufficient length to act as a lever, and also be able to tolerate the effects of piston action and friction.

The characteristics of an "ideal" above-knee stump, *i.e.* one that best fulfils the required functions, and lasts longest without showing signs of deterioration, are outlined in the paragraphs which follow.

Position of Operation Scars.—The operation scar should run across the posterior aspect of the stump, about 1½ inches above the cut end of the femur. In this position it will lie upon soft tissues and will not be damaged by piston action, or friction with the socket of the limb. Osteophytic outgrowths, or spurs, usually grow from the postero-internal aspect of the cut edge of the bone, and, in most cases, their direction of growth is upwards and inwards. The spur causes no trouble with the amputation scar in the position described. The sciatic nerve should

* E. Muirhead Little, F.R.C.S.: Artificial Limbs and Amputation Stumps, 1922.

have been cut sufficiently high to prevent it from becoming involved in the scar tissue.

Scars in other positions have the disadvantages that if they are on the anterior extremity of the stump they are subjected to friction with the front of the socket and, if terminal, to tension due to piston action, and if sepsis occurs there is a great risk of adherence to the bone. The region of the ischial tuberosity and all other pressure-bearing surfaces should, of course, be free from scar tissue.

Length.—The practice of the Ministry of Pensions is to measure all thigh stumps from the tip of the great trochanter to the end of the bone, whereas the measurements of the Limb Makers are from the perineum and may be termed "fitting measurements."

Measurements of thigh stumps referred to herein are taken from the tip of the great trochanter. It was formerly advocated that as much bone as possible should be left in thigh stumps ; one authority regarded a trans-condylar amputation as the best for a stump above the knee, whilst another stated that stumps should be as long as possible. The arguments in favour of long stumps were : (1) the longer the stump the better the leverage, and (2) "end-bearing" (i.e., the taking of weight by the end of the stump upon a pad in the socket of the limb) was a recognised practice in limb-fitting and for this the very long stump was specially suitable. Obviously a long stump has a greater power of leverage than a short one, but since experience shows that the long stump is apt to deteriorate more rapidly and to cause more trouble, the advantages of a little extra length are more than counterbalanced by the shorter stump, especially if adequate leverage can be provided.

To facilitate the practice of fitting end-bearing, which was considered to have merits, stumps were at one time formed with a pad of muscle to cover the end of the bone. These pads, however, gave much trouble; most of them atrophied and ceased to function; and it is now found best to cover the bone-end only with skin and enough tissue to maintain the circulation in the flap. Muirhead Little,* writing of war pensioners and the years 1914–1915, gives statistics of end-bearing which show that in 22 cases of amputation in the upper third of the femur, 4·5 per cent., and in 316 amputations of the middle and lower thirds, 43 per cent., were originally fitted with end-bearing. After a time, however, it was found that in 27 per cent. of the cases this fitting had been discarded as the wearers felt more comfortable without it. Records of all limbs supplied to war pensioners from 1927 to 1938 shew that amongst 883 short-thigh amputees only two, and out of 3,090 with long-thigh stumps only seven, continue to use end-bearing, and in none of these is the whole weight actually taken on the stump end, for all are fitted on the ischial tuberosity. It therefore seems clear that weight should not be taken on the cut end of the bone; and the fitting of end-bearing, or partial end-bearing, may have been due to a former lack of proficiency in securing an accurate and comfortable ischial bearing. No new cases are now fitted with end-bearing.

Apart, however, from end-bearing, long stumps do not tolerate the limb for so long as do shorter stumps, and, in most of them, circulatory disturbance occurs sooner or later. The majority of the long above-knee stumps in war cases have in fact been re-amputated; sepsis undoubtedly accounted for the short life of certain of them, but in many instances there was no such cause.

The ideal length for an above-knee amputation is from ten inches for a

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* Op. cit. (p. 15).

short, to twelve inches for a tall person. The chief flexor muscle, the iliopsoas, owing to its high insertion, does not affect the length of the stump, and a stump of ten to twelve inches will include sufficient of the insertions of the adductors and abductors to maintain an even balance of power in the stump. A stump of this length is sufficiently powerful to do all that is required of it. Moreover, it can be fitted with whatever type of above-knee limb is most suitable for occupational or other reasons, whereas, with a longer stump, the choice of limb, type of control, etc., is limited, very often to the detriment of the patient.

Configuration.—In general contour the stump should be conical, taper downwards, and have no redundant tissues; in fact the stump is better if it can be described as poorly covered. Such stumps never seem to give trouble, unlike those that are fat and flabby which can cause much trouble for reasons which will appear later. During the amputation, steps should be taken to prevent subsequent hæmorrhage as far as possible: the time spent in tying each bleeding-point is not wasted.

After-Treatment.—The stump should not be supported in bed on a pillow or sand-bag, as this only results in a flexed stump which interferes with comfortable fitting and efficient use of the limb. Some surgeons used to advocate massage and active and passive movements at the earliest possible moment after amputation, followed by a very early fitting with a temporary prosthesis; but the surgeons of the Ministry of Pensions, remembering that the patient and his stump have suffered severe trauma, have believed that rest and freedom from any further trauma are the first essentials. Massage undoubtedly helps to restore muscle tone and to improve the circulation but, nevertheless, trauma excites the nerves and should be allowed to settle down, and massage and passive movements at this stage tend to produce an irritable stump.

Later on, however, the patient may be advised to begin active movements of the stump, and he can usually be trusted not to do so to the extent of causing pain. The movements he carries out will be sufficient, for the time being, to start a restoration of muscle tone, circulation, and joint-freedom, and passive movements should not be attempted. The post-operative congestion at the extremity of the stump will disappear as the collateral circulation is established, but bandaging is useful and should be applied firmly at the actual extremity of the stump, the pressure being eased as the bandage is carried upwards. The bandage may be pinned to the underclothes when the patient begins to get about on crutches, or a stump sock may be worn over it, similarly attached.

When using crutches the patient should swing the stump and learn to perform the routine movements of flexion, extension, abduction, and adduction.

Tests of stump before fitting of limb.—After a time, which varies very much and depends largely upon the original cause of the amputation, the presence of prior sepsis and its extent, etc., the stump will be ready for the fitting of an artificial limb, of either a temporary or permanent variety. Before any attempt is made at fitting, however, the stump should first pass the following tests:—

(*a*) *The scar* must be soundly healed and consolidated, not thinly glazed over.

(*b*) *The stump* must submit, without pain, to fairly heavy handling, as an indication that the nerves have settled down. This test is important and omission may lead to trouble. Complaints

of occasional " jumping ", or consciousness of the " foot ", need not delay fitting, provided that the foot-sensation is one of discomfort rather than pain.

(c) *The collateral circulation* must have been established and there must be no remaining terminal œdema.

In uncomplicated cases these conditions are fulfilled within $2\frac{1}{2}$—3 months from the date of the amputation.

2. TEMPORARY PROSTHESES FOR AMPUTATIONS OF THE LOWER EXTREMITIES

A temporary prosthesis may be supplied for various reasons to a lower extremity amputee before the fitting of a permanent limb, and the length of time it is worn depends on the reason for its use. During the latter part of the Great War, however, and for several years afterwards, there seems to have been considerable difference of opinion on how soon the temporary prosthesis should be fitted and on the results of wearing it. Moreover, several different types of prostheses were used, such as the fibre pylon and a pylon made with an adjustable leather socket. In the Ministry of Pensions Limb Fitting Centres the plaster pylon has now superseded all other types, and it alone will be considered here.

Stump-Shrinkage.— However conflicting were the opinions at one time on the value of the temporary prosthesis, all agreed that its main function was to accelerate the shrinkage of the stump, and that is now the chief reason for its use. The stumps of all primary above-knee amputations, re-amputations, and to a lesser degree below-knee amputations, shrink very rapidly when the patient starts using an artificial limb, and the greater the use of the limb the greater and more rapid is the shrinkage, up to a stage at which the stump becomes more or less stabilised. This shrinkage is in almost all cases uniform, affecting the whole stump proportionately, a circumstance that is fortunate from the limb-fitter's point of view since it is essential for the welfare of the stump that the shrinkage, as it occurs, should be treated either by the addition of stump socks or by the adjustment or refitting of the socket of the limb. Much harm can be, and often is, done to the stump by the continued use of a socket which, through changes in the stump, has ceased to fit, and because the patient, on account of inconvenience or expense, has not attended a limb-maker for adjustments and received the correct treatment.

All stumps, however, do not shrink at the same rate, nor to the same extent, partly, perhaps, on account of the different ways in which patients use a limb. It is thus impossible to predict how much a particular stump will shrink and only by constant observation can the rate of shrinkage and the time of its apparent cessation be judged. Normally, an above-knee amputation, if a primary case, is fitted when wearing one stump sock, and, as the stump shrinks, the patient will add socks up to perhaps four, by which time the limb will feel heavy and the stump very hot and often uncomfortable. As the thickness of one woollen sock on an average stump adds about half an inch to its circumference, by the time the four socks are being worn the stump will have shrunk about two inches and, owing to the discomfort of so many socks, a new socket will probably be required. Assuming that the patient makes good use of the limb, this amount of shrinkage will normally take place in four weeks; but rather than incur the expense of fitting a new socket, if a permanent limb is in use, some patients prefer to go about in discomfort, thus risking harm

to the stump, although these considerations would not apply to pensioners fitted at the expense of the State.

Plaster Pylons.—A temporary prosthesis, such as a plaster pylon, is a very cheap appliance, and if shrinkage occurs whilst it is being worn, the socket can be padded with felt, or renewed in its entirety, for a few shillings. If, therefore, the patient wears such an appliance whilst the stump is shrinking, the socket of his permanent limb should require little alteration for some time to come, and from this point of view the value of a temporary prosthesis is unquestionable.

Other claims made on behalf of the temporary prosthesis are, however, not so manifestly justified. By some, the plaster pylon used to be, and still is, considered to have some curative value and to accelerate the recovery of the stump after amputation, thus expediting the fitting of a permanent limb. This it cannot do, for if the stump is not ready for a permanent limb it cannot be ready for any other form of limb, particularly one which is heavy, ill-balanced, and with which the patient cannot walk naturally. Again, it has been strongly recommended that the temporary appliance should be fitted as soon as the scar is healed, or even before it is healed, on the ground that a patient who is allowed to use crutches while waiting for a permanent limb loses the desire to walk with an artificial limb. In support of this view, however, there seems to be little or no evidence. In favour of fitting a temporary limb it has also been urged that the patient's hands are left free, crutches and the risk of crutch paralysis being eliminated. This is no doubt true, but at the Ministry's centres crutch paralysis is now almost unknown as elbow crutches are supplied when necessary.

It is to be remembered that the plaster pylon does not teach a patient to walk properly, nor does it teach him a correct sense of balance, and, if it is used too long, the abducted or rotary form of gait develops, from which it may take a considerable time to recover. This bad gait may not, in earlier days, have compared so unfavourably with that of those using fully-articulated legs; but through improvements in design, construction, and methods of fitting artificial legs, patients can now, if they will, walk so naturally that it is often difficult to recognize that they have suffered amputation.

In deciding the time that should elapse between the amputation and the fitting of a temporary prosthesis, it must be borne in mind that the most important requirement for a stump after amputation is a peaceful convalescence, without which an irritable stump may be expected in the future. The stump must, therefore, be protected from trauma of any sort until it can tolerate it without detriment. The chief aim should be to allow the nerves of the stump to settle down after the trauma they have endured; anything which interferes with this merely irritates and prolongs the convalescent period, jeopardising the future value of the stump. No prosthesis of any sort should be fitted until the stump has settled down in every respect, by which time it is ready for a permanent artificial limb. If a temporary prosthesis is then considered necessary it may be provided without risk of harm to the stump if (1) the socket of the pylon is fitted with the accuracy and knowledge used in the fitting of a socket of a permanent limb; (2) whenever possible the pylon is fitted by the limbmaker who will subsequently fit the permanent limb; and (3) the patient's stump is examined, whilst wearing the pylon, not less often than once a fortnight.

In the past it has been suggested in some quarters that no great experience is necessary for the construction of a temporary prosthesis, but

this is a wholly mistaken view : an incorrectly fitted prosthesis can do much harm to a stump and the fit of the pylon socket should be as accurate as that of the permanent limb. For this reason it is recommended that the pylon should be made only by an experienced limb fitter, and, if at a later date he can build the permanent limb, the advantages are obvious. He will have studied the stump, watched its rate of shrinkage, general conformation, and reaction to the use of a limb, and the experience thus gained will be of great assistance in the construction of the permanent limb.

The patient should be advised to use the pylon at first for an hour or so a day and then gradually and daily to increase this time. When once the patient has commenced using the pylon he should continue with it so long as the stump remains sound, for otherwise the stump will increase again, and many days will be wasted. When the pylon is in use the stump should be inspected at intervals to ensure that the patient is making proper use of the appliance and thereby effecting shrinkage of the stump. Observation should be made to see that stump socks are added as and when required, and that the stump is suffering no damage.

Temporary prostheses are now used only for shrinkage, or, very occasionally, for experimental purposes when there may be some doubt of the ability to make use of an artificial limb. For such cases a plaster pylon is most useful and cheap, and with it various methods of fitting can be tried, and the reaction of the stump watched, so that the best method is found. For this, however, the services of a very experienced fitter are required. Plaster pylons are now mainly used for the above-knee stump, and if the stump is short and unable to control the pylon unaided, a pelvic band may be added. Pylons are not usually supplied for disarticulations at the knee, nor for what are known as kneeling stumps, because for these they cannot be constructed so simply or cheaply as for other above-knee stumps, and the extra cost is hardly justified for a shrinkage which can, in these cases, be obtained by firm bandaging and adjustments to the socket of a permanent limb. For below-knee amputation stumps that are able to take tibial bearing, a pylon is practicable, but below-knee stumps rarely require more shrinking than can equally well be attained by firm bandaging. Tibial bearing, however, is not always advisable for below-knee stumps, and if an ischial-bearing corset is fitted to a temporary prosthesis the cost is considerably increased.

The best method of constructing plaster pylons for above-knee amputations, and the one that gives the most accurately fitting socket, is as follows :—Circumferential measurements are taken of the stump, commencing one inch below the ischial tuberosity and continuing downwards every two inches or so. These measurements are then checked, and a master-socket of metal is found that corresponds with them as nearly as possible. Plaster bandages are then wound round the metal socket on its outer side until the required thickness of plaster is obtained, after which the external plaster socket is withdrawn from the metal socket and will represent the shape of the stump. The plaster socket is further reinforced with plaster on the outer side, and bound by plaster bandages to the upper ends of two ash sticks, placed laterally, which, as they extend downwards, converge, and are countersunk and screwed into a wooden peg-base about four inches high. At a point a few inches below the bottom of the plaster socket the two ash sticks are joined by a metal rod, or distance-piece, upon which revolves a wooden cylinder. Suspenders, worn over the shoulders, are attached, front and back, by buckles to a piece of webbing which passes under the wooden cylinder on the distance-piece.

The older method of making plaster pylons differed only in the manner in which the socket was constructed. This, however, is a very important difference. A cast of the stump was taken over a stump sock and this cast was then reinforced and thickened to the required strength and bound to the ash sticks in the usual way. The resultant socket gave the shape of the stump when in relaxation and not under compression such as is applied when wearing a limb, and, therefore, it could not fit accurately and did not effect shrinkage in an efficient manner.

For plaster pylons for below-knee amputation stumps that can take tibial bearing, a cast of the stump is now first taken over a stump sock and when removed from the stump is filled with plaster to obtain a male cast. The male cast is then built up with plaster added to appropriate sites that can only be ascertained by long experience, and, when it is finally set and hard, a female cast is constructed which represents the shape of the stump in compression. This final cast is then reinforced and bound to two strips of mild steel that form the lower portions of the knee joints. Two more pieces of mild steel are then attached to the upper extremities of the lower steels to form knee-joints, and to these upper steels is attached a thigh corset made of vulcanised fibre, which can be laced up anteriorly upon the thigh. Webbing shoulder suspenders are attached, front and back, to this corset.

Vulcanized fibre does not lend itself to the construction of a satisfactory ischial-bearing corset, as it is difficult to mould to the required shape, and when this fitment is required a leather corset, blocked stiff and shaped with an ischial roll at its upper extremity, would add much to the cost of the temporary appliance and might render it uneconomical. For this reason, therefore, temporary prostheses are not supplied for below-knee amputations for which ischial-bearing is necessary, but, instead, the permanent limb is supplied and the socket refitted when shrinkage takes place.

Note on the Master Socket.—The contractors to the Ministry of Pensions for the supply of artificial limbs, as a result of long experience with many thousands of above-knee amputations, have obtained statistics of stump measurements taken under compression and in relaxation. These measurements fall into certain groups, and for each group a standard metal socket has been constructed. The measurements of the individual case are represented approximately in these groups and their master sockets, so that from them a plaster socket can be constructed that, after the necessary individual adjustments, gives a perfect fit.

3. LIMBS FOR THE IDEAL ABOVE-KNEE STUMP

Classification.—The classification of artificial limbs suitable for the ideal above-knee stump is not simple and there are several ways of grouping them. A primary division is into *Metal Limbs* and *Wooden Limbs*, the former group subdividing by the manner in which the limb is suspended to, or controlled by, the wearer into :—(a) *pelvic-suspended or stump-controlled limbs*, suspended from the pelvis, such as the double-swivels pelvic band limb and the compensating pelvic band limb; and (b) *shoulder-suspended limbs*, such as the central-knee controlled limb.

All wooden limbs are shoulder-suspended and include the Ministry Standard wooden limb, and the various Anglesey types. Wooden limbs have been manufactured for above-knee amputations for very many years, though it is difficult to trace any reference to them earlier

than the year 1850. Metal limbs, on the other hand, are comparatively recent, having been introduced during the early days of the Great War.

The advent of the metal limb was received with some criticism, both from limb manufacturers and from patients, and their cost made them at first available to only a few, but by improved design and construction this has been reduced. Another objection was the light weight of the leg, which was thought likely to hinder its efficient use, but experience has shown this fear to be unfounded. Actually, the difference in gross weight between a metal leg and a modern wooden leg is not great, but the metal leg is better balanced and the " swinging weight " (or weight below the knee) is less, thus causing less fatigue to the stump. In 1921, when metal legs were still in their infancy, and had not been used long enough for their full value or mechanical lasting powers to be assessed, they were not supplied in large numbers, and Muirhead Little (1922) in an introduction to his book,* stated " . . . the battle of the legs is still raging and at the moment aluminium seems to be in the ascendant. . . ." Nowadays wooden legs for above-knee stumps are ordered only (1) in replacement of old wooden legs of patients who refuse to try the metal leg, or (2) when expense is a primary consideration, or (3) for those who prefer the Anglesey or semi-Anglesey action, which is not obtained in metal legs.

Pelvic-suspended or stump-controlled limbs.—This type of limb is suspended mainly, if not entirely, from the pelvis by means of a double-swivel pelvic band, a compensating pelvic band, or other form of pelvic suspension. The limb is so constructed that the knee joint does not swing entirely freely, but is fitted with an adjustable brake. To walk properly with the limb the patient must have a good stump, capable of controlling the artificial leg and moving it into any desired natural position without aid from shoulder suspenders. Furthermore, the stump must be able to overcome a moderate amount of friction in the knee, and the ideal stump should perform all these functions. With a stump-controlled limb walking can be more natural than with any other type, if the patient takes the trouble to learn to walk properly. For some patients, however, certain conditions of occupation and medical complication may make this form of limb unsuitable even with an ideal stump.

Shoulder-suspended limbs with central knee- or other control.—This alternative form of limb is suspended from the shoulders and actuated by what is termed Central Knee-Control. With this type the stump is not necessarily called upon to exert itself to any great extent. The shoulders of the patient are in direct connection with the knee of the artificial limb through the medium of suspenders and what are termed roller cords. The patient can move the limb by lifting his shoulders and can also, when actually walking, cause the shin to extend upon the knee. It will be observed that although this limb is commonly called the central knee-controlled limb the main control is from the shoulders.

This method of suspension and control, introduced from America, has been in use for many years and is extremely useful for the requirements of those who, for various reasons, cannot, or should not, be supplied with a stump-controlled leg. Nevertheless, the stump-controlled limb is undoubtedly gaining in popularity with greater experience in its uses and advantages and owing to improvements in design and con-

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* Op. cit. (p. 15)

struction. In the year 1927, 154 legs were supplied with central knee-control and 271 that were stump-controlled. In the year 1936, 123 central knee-controlled legs were supplied and 319 stump-controlled legs.

General principles of construction of metal and wooden limbs.—(1) *The standard "set-up" for metal limbs.*—Artificial limbs cannot be standardised for the fitting of the socket, as each case requires individual treatment; but it has now been found possible to standardise, to a certain extent, the rest of the limb with the result that production costs have been lessened and, for example, a central knee-controlled leg can be converted to a stump-controlled leg in a few minutes, at a comparatively small cost, whereas formerly an expensive reconstruction of the limb would have been needed. Whatever type of limb is ultimately required for a given case it is constructed from a standard "set-up," consisting of the knee piece with knee spindle, shin, and ankle-base with joint and foot; the socket and container and the final accessories are then added.

(2) *The Socket.*—This is the portion of the leg into which the stump is fitted; it may be constructed of willow or metal. When made of metal the material used is either duralumin, which is an aluminium alloy, or alclad, which is duralumin surfaced with a fine covering of pure aluminium.

If a limb is held upright and the socket viewed from above, the contour of its top is roughly triangular in shape, the base being formed by the medial, or inner, margin, and the apex being at the site of the great trochanter when the stump is inserted. The anterior side of the triangle forms a very gentle curve whilst the curve of the posterior side is more pronounced. Along the base of the triangle the top of the socket is rolled over, so as to make a shelf which is very narrow anteriorly in the adductor region, becomes broader where the ischial tuberosity rests, and spreads out still further just posterior to the ischial region. On the other two sides of the triangle the shelf fades away gradually to become a straight edge which, in a metal socket, is surmounted, as is the whole upper margin of the socket, by a beading.

The anterior border of the socket, i.e., the portion extending from the adductor margin to the great trochanter, does not run horizontally but rises, from within outwards, in the direction of a line drawn from about one inch below the highest point of the perineum. This line is approximately parallel with Poupart's ligament. The posterior border of the socket is also not horizontal, but tends to fall slightly from the apex on the outer side to a point where it meets the most posterior portion of the inner side.

The shape of the socket, below the level of its upper border, tends to become more and more circular towards its lower extremity according to the peculiarities of the individual stump.

In its early days the metal limb was usually fitted with a willow socket as patients objected to a socket made of metal which they thought would be cold and uncomfortable. Now, however, more metal than willow sockets are used; in fact willow sockets for metal limbs are only supplied to patients who refuse to try the other type. The advantages of a metal over a willow socket are, briefly, as follows :—(*a*) It is lighter by several ounces and, being metal, can be perforated all over, in order to give ventilation to the stump, without weakening the socket. (*b*) Its thickness is very much less, and its lesser width along the inner side is of

great advantage if the patient is adipose, or has a fat and flabby stump. (*c*) Stump flexion of five degrees and over can more readily be accommodated. (*d*) It is more hygienic, for it can be washed and is provided with ventilation. (*e*) Necessary adjustments can be effected within reasonable limits. (*f*) If a general stump shrinkage has taken place the socket can be reduced by $\frac{3}{4}$ inch in circumference, or increased by the same amount the stump becomes larger. Whilst a wooden socket can be made smaller by padding, this makes it still hotter and heavier to wear; and small local adjustments, once effected, cannot be altered satisfactorily.

The socket should, whenever possible, project about one inch beyond the stump extremity at the bottom, and it is only when markedly flexed stumps are being dealt with that this cannot be achieved.

(3) *The Container.*—This is the thigh piece into the top of which the socket is riveted and fixed at the required angle to allow for any present flexion or abduction. At its lower extremity the container is riveted into the knee-piece.

Two types of container are in common use :—(*a*) The " shaped " container, and (*b*) the " straight " container.

The " shaped " container, in its upper two-thirds, is of somewhat larger circumference than the socket within it, except, of course, at the extreme top edge. The general contour resembles as nearly as possible that of the natural thigh, which gives a pleasing effect to the leg as a whole, but in itself is of no advantage, except in a case with great flexion or abduction of the stump, when the stump can be accommodated by tilting the socket within the container, without producing any deformity visible to the eye when the leg is worn. In normal cases the disadvantage of the shaped container is that it must be carried as high up the socket as possible, thereby increasing the weight of the leg as a whole. The " straight " container is the best for all normal cases as it is lighter and need not be carried any further up the socket than is consistent with safety. When a wooden socket is fitted this type alone is used.

(4) *The Knee-Piece.*—The artificial knee is made to represent the shape of the natural knee. Within the knee-piece (Fig. 1) will be found, on either side, a " Housing " or " Boss," into which is fitted, projecting inwards, a " Journal-Bearing." A steel spindle is passed through these bearings on either side, lying transversely across the knee-piece and projecting slightly beyond it.

(5) *The Shin-Piece.*— This is prepared from a solid-drawn tube of duralumin and pressed out to give the contour of the natural shin. Many different sizes are made, of varying lengths and calf-circumferences, so that the requirements of every patient, from a child of 5 to an adult man or woman, can be met. Into the upper end of the shin is riveted a shin-casting which has two lugs projecting upwards on either side above the top of the shin, drilled and tapped to receive the projecting extremities of the knee-spindle, and a further lug, situated upon the casting centrally and posteriorly, to which is attached the lower end of the back-check ligament. The upper end of the back-check ligament is attached to a corresponding lug situated centrally upon the posterior external aspect of the knee-piece. When the knee and shin are assembled the back-check ligament prevents hyperextension at the knee.

At the lower extremity of the shin will be found bosses which represent the malleoli, and into its open end is fitted the ankle-base, made of alpax

metal. The ankle-base houses, on its under surface, the roller-bearing ankle joint, which consists of a barrel of metal and a steel spindle, between which are inserted silver-steel rods. From the under surface of the barrel a steel prong passes downwards through the body of the foot to be attached to the latter by a conic nut (Fig. 2).

(6) *The Foot.*—The upper part of the wooden body of the foot is suitably carved out to receive the ankle mechanism and the two main foot rubbers, called the heel and instep rubbers, the former cylindrical and the latter flattened and fitting into the fore-part of the foot. The instep rubber plays a very important part in the use of the leg and it will be referred to later. In front of the instep the toe-piece is cut off transversely, and slightly obliquely, and the two parts are joined by a hinge joint of balata belting fitted to the under surface of the foot. The cut faces of the foot and toe-piece are slotted and fitted with a toe-rubber so that a metatarsal joint is formed. The under surface of the toe-piece is covered with felt, and that of the heel with rubber or felt, and the whole foot is then covered with horsehide.

There is an alternative type of foot called the "Rubber Foot" (Fig. 4). This differs from the wooden foot (Fig. 3) in that the forepart of the wooden foot is replaced with rubber, rendering the toe joint unnecessary, and a thin sheet of rubber is carried round the rest of the foot over the wood. The rubber foot is about $3\frac{1}{2}$ ounces heavier than a wooden foot, and, though it may be a little more resilient in use, this advantage is so slight that it does not compensate for the extra weight.

The typical pelvic-suspended, or stump-controlled, limb.—A stump-controlled leg is one which is suspended from the pelvis by means of a pelvic belt, such as the *double-swivel pelvic band.* This band, as the illustration shows (Fig. 5), consists of a leather belt, reinforced by a short steel to which is attached the upper steel of the hip-joint running in a roller bearing. This steel articulates with a lower steel through the medium of a ball-bearing joint. The lower part is riveted approximately to the centre of a stirrup-shaped piece of duralumin known as the swivel-strip. The extremities of the swivel-strip are attached to the socket of the limb when a straight container is used, or through both socket and container when a shaped container is used, the attachment being anterior and posterior. A single shoulder brace passing over the shoulder opposite the amputation is usually required as an auxiliary suspender. When a limb is to be put in action solely by the stump, the journal-bearing joint in the knee is much too free and the patient has not sufficient control over the swing of the shin. To overcome this an *adjustable knee-brake* is fitted inside the knee-piece. This consists of a duralumin drum, attached to the steel knee-spindle, and around it is fitted a steel band lined with whale hide. This band is contracted upon the drum by turning a small spindle in the front of the knee-piece by means of a small clock-key. A ratchet is also fitted to prevent slackening of tension. With this fitment any degree of friction can be applied to the knee according to the requirements of the patient.

This is the standard type of knee-brake. The *button knee-brake* has a similar action, but the contraction on the drum is applied by sliding a button up or down on the outside of the container, the button being attached to a lever on the brake band by means of a flexible wire cable. In *the wheel knee-control brake*, the contraction on the drum is similar but is applied by turning a large-diameter wheel, with knurled edge, which projects slightly through the knee-piece anteriorly.

Even though the knee brake is used there is still a tendency for the shin of the leg to flex too much, or to lag, when extension at the knee is required, and there are two methods of overcoming this :—(1) *A pick-up* consisting of a leather thong is attached to the front of the shin. To this is attached an elastic accumulator which in its turn is attached to a stud on the pelvic band. (2) *An internal knee-spring* is fitted within the knee piece in such a way that flexion at the knee compresses the coiled spring, which afterwards assists the shin to extend on the knee. The addition of these parts to the set-up constitutes a stump-controlled leg.

The double-swivel pelvic band, as described, allows rotation at the pelvis in a horizontal plane. The ball-bearing hip joint allows of flexion and extension at the hip joint and the swivel-strip attachment allows of a movement of adduction and abduction of the leg as a whole. There are several modifications of this hip joint for patients whose stumps require more support.

An alternative form of stump-controlled limb incorporates the *compensating pelvic band.* To fit this band it is necessary to add two small rollers laterally, one on either side of the socket five or six inches from the top. Two cords or thongs of leather pass through these rollers, and cross each other in front and behind to be attached above to a pelvic belt as shown in the illustration (Fig. 6). The belt has a thin strip of metal incorporated in the leather and it is cut and shaped so that it lies comfortably upon the pelvis and lower abdomen. A standard or other form of adjustable knee-brake is usually necessary with this form of suspension.

The utility of this method of suspension and control is limited. It is only suitable for an ideal stump and for a patient whose figure is neither too fat nor too thin. If the patient is adipose, or very thin, the belt cannot be retained in position and therefore control of the leg is lost.

The shoulder-suspended limb.—To adapt this type of limb for central knee-control two apertures must be cut in the container, one in front and one behind, just above the point where the container joins the knee-piece (Fig. 7.). To the knee spindle is attached a bracket, the arms of which pass forward in the knee piece in front of and above the level of the spindle; the arms hold a fibre or metal roller (Fig. 8.). Two leather thongs pass under this roller and out through the front and back apertures in the container to be carried upwards on the outside of the container and socket for attachment to hooks fitted to double suspenders passing over both shoulders of the patient. When the shin is flexed upon the knee a bracing of the shoulder will cause the shin to extend. The knee action must be very free in these limbs, and no form of knee brake is normally required, but an internal knee-spring, or knee-lever, to assist extension of the shin is sometimes an advantage.

Some patients who require shoulder-suspended limbs do not like the central knee-control and for these there are three other methods of suspension :—(1) *Moore's Outside Control :* In this method two straps, one inch wide and twelve inches long, are attached to the shin, one on either side anteriorly. These lie up along the container and to their upper extremities are fitted " Housed Rollers." Roller cords pass through these to be attached to the double suspenders. (2) *Four Point Suspension :* Two 2-inch wide elastics are attached to the top of the socket at the front and two at the back. These in turn are attached by hooks to the double suspenders. No knee brake or spring is required but occasionally

an elastic pick-up is fitted from the top front of the shin to the front of the socket. (3) *Three Point Suspension:* In this device two elastics are fitted in front and one behind; otherwise the suspension is the same as described above.

Ministry Standard Limb.—This is the type most commonly in use and consists of a wooden socket and thigh-piece, keyed into a wooden knee-piece, through which runs a knee-bolt lying in leather bushes on either side of the knee-piece. There being no ball-races in the knee of a willow limb, the action is slightly slower. The willow shin is attached by side-straps of metal to the projecting ends of the knee bolt, and hyperextension at the knee is prevented by a back-check ligament, similar to that used on metal legs. The ankle joint is of the roller-bearing type, adapted for use in willow legs. Being a shoulder-suspended leg the same alternatives for control are available as in metal legs.

The Anglesey Limb.—There are two types of Anglesey legs:—the "Full" and the "Modified." In the "Full Anglesey" (Fig. 9) the knee-piece and top of the shin are articulated by means of a tenon-and-mortice joint, as are also the lower end of the shin and the foot. The knee is connected to the foot by catgut tendons in such a way that flexion at the knee causes dorsiflexion of the foot, whilst extension at the knee produces extension at the ankle. The "Modified Anglesey" from socket to mid-shin is similar in construction to the Ministry Standard Limb, and the foot and ankle are of the tenon-and-mortice type with short tendons. The suspension of the Anglesey type of limb is usually by means of the three- or four-point suspension method, with, in many cases, the addition of a pick-up from the shin to the socket.

4. THE SELECTION OF A LIMB FOR THE IDEAL ABOVE-KNEE STUMP

As a stump conforming to the "ideal" standard described could be fitted with, and control, any of the limbs with any of the types of suspension and control mentioned so far, the choice for an individual case might appear to be a matter of no great importance and no great difficulty. The selection of the most suitable limb for a particular case is not, however, easy, but requires experience, a good knowledge of all the types available, and a study of the physical and mental capacities and occupational requirements of the patient.

In past years experiments were made with different types of suspension and control, and, though it would be incorrect to say that the days of experimentation on these lines are over, a groundwork of knowledge has now been attained from which it is possible to decide on the type that will be most suitable for the average case. Despite this, difficulties in choice can, and do, arise on the finer points of differentiation between certain types, and border-line cases will occur that often can be decided only by yielding to the patient's request to try out a certain method during the fitting stages, particularly should he previously have worn an artificial limb and developed ideas of his own. Again, not uncommonly, a patient who has for years been thoroughly satisfied with his limb asks for a change in type of suspension or control, or of both, because another patient who has come to live in the same street walks, he thinks, better than he does. It is then not easy to convince him that the type of limb he is now wearing is, in fact, the most suitable for him, whilst that of his friend would, in all probability, diminish his efficiency. In general, whilst

experimentation is not necessarily inadvisable, the subjects for it must be very carefully chosen, if benefit is to accrue either to them or their fellow-amputees. Broadly speaking, 75 per cent. of amputees are very conservative in their ideas and, once fitted satisfactorily, will not agree to any change, but the remaining 25 per cent. are always anxious to try something new or different, regardless of its suitability.

It is evident that there are no laws for the selection of a limb, and in dealing with the average case there are certain general indications which may be prefaced here by a repetition of the limbs and types of control from which selection must be made. The choice lies amongst :—

1. Metal limbs supplied with either :

(1) Pelvic suspension, which includes :
- (*a*) The double-swivel pelvic band;
- (*b*) The compensating pelvic band;

or (2) Shoulder suspension, which includes :
- (*a*) Central knee-control;
- (*b*) Moore's outside control;
- (*c*) Four-point suspension;
- (*d*) Three-point suspension.

2. Wooden limbs with shoulder-suspension as in (2) above.

Choice of a wooden leg can normally be excluded since, as already explained, it is not prescribed for primary above-knee amputations except for those civilians who cannot afford the slightly more expensive metal limb. If a wooden limb must be prescribed it will be supplied with one of the four methods of suspension given under 1 (2). The standard willow limb and the Anglesey types are not normally used for primary cases and are thus reserved for those patients accustomed to them and who do not wish to change when a new leg is required. The suspension of the Anglesey type may be by method (2) (*c*) or (2) (*d*). For metal legs, choice must be made between the stump-controlled and the shoulder-controlled.

The pelvic-suspended stump-controlled leg.—(1) *With double-swivel pelvic band.*—This band is suspended from the pelvis, but a single brace, passing over the shoulder opposite to the side of amputation, is usually fitted, though not always essential, for the purpose of keeping the pelvic band horizontal. Movement of the shoulder has no action upon the artificial leg and therefore the stump alone has to perform all the necessary actions in walking. The design of the pelvic band, hip-joint, and swivel attachments permits all the normal movements of the artificial leg, and yet, at the same time, undue movements are controlled by the pelvic band. The knee-brake allows of an adjustment of friction to suit all cases.

With this type of limb we have a more natural gait than is provided by any other type, but a certain amount of intelligent study and practice is necessary for the best results. It would be wasted upon patients of little intelligence, or those who take no interest in their gait and appearance : indeed, it would develop a gait worse than that with a shoulder-controlled leg. Although, with pelvic suspension, movements of the artificial shin and the foot cannot be carried out quite so readily as when the leg is suspended to the shoulders, yet great freedom of the shoulders is allowed, and there is an absence of constriction of the chest wall which is advantageous for those who, in sport or in occupation, need such freedom, and for those who suffer from respiratory affections. If the patient has the mentality that can make good use of this type, and if he requires

shoulder freedom but has a stump deficient in length or power, his needs can be met by eliminating the top swivel movement and/or the movement of abduction and adduction. The stump must, however, be of sufficient length and power to actuate the knee mechanism.

(2) *With compensating pelvic band.*—This type of suspension provides a similar form of stump-controlled leg and has the advantage over the double-swivel pelvic band that there is no metal hip joint attached to the leg and it is, therefore, lighter and cooler to wear. Nevertheless, and although all the movements of the double-swivel band are present, there are, unfortunately, disadvantages that cannot at present be overcome, and the compensating band can be used only for a limited number of patients. It is unsuitable if the patient is too fat or too thin, or if the stump is short. Further, the friction of the cords passing under rollers on the socket is sometimes considerable, and has been objected to by patients. In short, for those who can overcome the friction and are of the right build, the compensating band is an excellent method of suspension, but the uncertainty of success has made surgeons prescribe it only in rare cases.

A somewhat modified form of this belt is used with success by women patients, and is the usual method of suspension for women who object to suspenders over both shoulders.

The shoulder-suspended leg.—(1) *With Central Knee-Control.*—With this type of control and suspension, roller cords pass under an eccentric pulley within the knee-piece, to be attached, front and back, to suspenders passing over both shoulders so that movements of the shoulders have a direct effect upon the limb. The act of bracing the shoulders causes the leg to be lifted from the ground and, when the knee is flexed, bracing the shoulders causes the shin to extend upon the thigh owing to the eccentric position of the pulley in the knee. No special degree of intelligence is required to use this type, nor need the stump be exerted to any degree. The connection with the shoulders makes this limb very quick in action if speed is required without any exertion upon the stump; but, if no use is made of the stump to assist the movements of the limb, the resultant gait is often very bad indeed, the patient lifting his shoulders abnormally at each step and swinging the limb forward in pendulum fashion. If, however, the stump can give some assistance then the gait is much better.

This type of control can, therefore, be prescribed for :—

(*a*) the patient who is indifferent to his gait and appearance when using a leg, and is unlikely to take the trouble to learn to use a stump-controlled leg;

(*b*) the patient who, through general debility, etc., is unlikely to develop sufficient power to utilise a stump-controlled leg without harmful effects from over-exertion;

(*c*) the patient whose stump may be ideal in length but deficient in muscular power;

(*d*) cardiac cases for whom any great exertion when walking is undesirable;

(*e*) patients who are constantly working amongst machinery and require a limb that can be moved rapidly and easily, and those who spend most of their time walking over rough and difficult ground, *e.g.*, farmers and platelayers on the railways.

(2) *With Moore's Outside Control.*—This type is designed for those who require central knee-control but whose stumps are so long that, if central control were fitted, the end of the stump would touch the pulley-bracket that rises about one inch above the knee centre. It provides an action approximating as closely as possible to central knee-control, but it is now rarely used, as it is, fortunately, rare to find a stump amputated so close to the knee-joint.

(3) *With Four Point Suspension.*—This type is used mainly for those wearing Anglesey-type legs, and for women patients in conjunction with a belt. It is a form of suspension rather than one of control, and therefore, does not, render the stump any assistance. It is not prescribed now for new cases.

(4) *With Three Point Suspension.*—This type is merely an alternative form of (3) above and is used for the same class of case.

5. EXAMINATION OF THE ARTIFICIAL LIMB—ADVICE TO PATIENTS—FAULTS IN ARTIFICIAL LIMBS

Examination of the artificial limb.—A new or refitted limb should be examined before the patient is allowed to take it away to ensure that :—

(i) the manufacturer has constructed the limb exactly in accordance with the requirements of the height of the patient;

(ii) the surgical requirements for fit of socket and alignment of leg have been met; and

(iii) the patient is able to make proper use of the limb and thoroughly understands its functions and their value.

Understanding by the patient of the functions and mechanism of the limb is important since modern limbs are fitted with a number of new attachments, such as adjustable knee brakes, compression springs, and knee locks, which cannot be appreciated without proper knowledge of their use. The limb-makers should instruct the patient on these points, but very often such instruction needs repetition and amplification by the time the patient attends with the completed limb to see the surgeon.

The examination of the limb should be carried out in a fixed, routine, and systematic manner. In describing this routine it will be assumed that the patient has been supplied with a stump-controlled limb, fitted with a double-swivel pelvic band, standard adjustable knee, internal knee spring, metal socket, and shaped container.

(1) *The fit of the socket.*—When examining a limb to discover what repairs of a mechanical nature are required it is customary to commence the examination at the top, i.e., the pelvic band, if one is fitted, and to work downwards to the foot, so that the risk of missing a part of the limb is negligible. This method cannot be adopted, however, when examining the limb on the patient, because the relative positions of the various parts of the pelvic band are dependent upon the correct relationship of the ischial tuberosity to the tuber margin of the socket and the examination must therefore commence at the socket.

When a primary-amputation stump is fitted only one stump sock is worn, since shrinkage may occur before much time has elapsed, and it is necessary to see that the patient has but one sock on the stump, for the wearing of two at this stage would indicate that rapid shrinkage had

occurred since the last fitting and that further examination would be required at an early date. For a patient who has worn limbs before, and whose stump may be considered more or less stable in shrinkage, it is not uncommon to fit two socks for comfort and to allow for slight variations in the size of the stump.

The position of the ischial tuberosity is next examined. It should rest upon the tuber-bearing of the socket in such a manner that the medial border of the tuberosity is flush with, or in the same vertical plane as, the lip of the socket. A minor degree of the weight will be carried upon the gluteal shelf of the socket by the gluteal muscles.

There should be no undue pressure of the socket in the adductor region and no marked bulging of tissues at this side. The top outer margin or rim of the socket must not press unduly upon the trochanter so as to cause chafing, and, finally, the alignment of the socket in the container must bear a correct relationship with the alignment of the stump.

If a flexed stump is fitted with a socket which is vertical in the container the patient may walk quite well at first, but later will complain of tiredness due to muscle strain, which limits the distance he can walk in comfort. Most amputation stumps of 10 to 12 inches show a slight degree of flexion, due to over-action of the psoas muscle, and the shorter the stump the more the flexion. Flexion, however slight, is now accommodated in the socket in all cases. Abduction or adduction of the stump must also be accommodated in the socket.

An error in the fitting of the stump in the socket may result in misplacement of the pelvic band.

(2) *The fitting of a double-swivel pelvic band.*—The nature of this band has already been described (p. 25).

The patient should stand erect, facing the examiner, who first ascertains the position of the centre screw of the artificial hip joint, this being the factor that decides the correctness or otherwise of the belt as a whole. Assuming the patient has a right above-knee amputation, the examiner will place his left forefinger behind the great trochanter, and his thumb in front of this bone, and he should find that the vertical centre-line of the female bearer coincides with the junction of the posterior two-thirds and the anterior third of the distance between his forefinger and thumb. This gives the position of the hip joint in the horizontal plane. The centre-screw of the joint should be found to be about $\frac{1}{2}$ inch below the highest point of the great trochanter.

The surface marking for the axis of the natural hip joint is a point at the level of the highest point of the trochanter and $\frac{1}{4}$ inch in front of it, but this marking is correct only when the patient's stump is exactly in the vertical plane. The fitting of the artificial joint at a lower level than the tip of the trochanter is due to the fact that the low fitting tends to draw the socket on to the stump, whilst the converse happens with a high fitting.

The pelvic belt itself should lie horizontally around the pelvis at a height-level determined by the length of the male steel of the hip joint. The length of this steel is itself decided by the ability of the patient to sit upright without his flesh being pinched between the top front lip of the socket and the lower edge of the pelvic belt. The patient should now sit in order that this may be verified. On standing erect once more the patient should bend to the left and to the right whilst the examiner notes that the upper and lower borders of the swivel-strip or stirrup do not foul the socket.

The patient should now walk, in order that it may be seen whether the turning out or in of the artificial foot is in excess of that of the natural foot. The flexion at the knee should be natural, without undue effort, and, when a pace is taken, the shin should not lag behind and the knee should extend with a smooth rapid movement, ready for the next pace.

When the patient is in the sitting position it should be observed that the top of the artificial and natural knees are in the same plane, and that the artificial knee is not projecting unduly in front of the natural knee.

(3) *The height of the limb.*—The height of the limb should now be verified, for which purpose the patient stands erect before the examiner, who has ascertained that there is no deformity of the lumbar spine. If the thumbs are placed on the anterior superior spines of the ilium, the thumb on the anterior superior spine of the amputated side will be slightly lower than that on the sound side. Normally there will be a drop of $\frac{1}{2}$ to $\frac{3}{4}$ of an inch on the amputated side, but no hard and fast rule can be laid down; each individual case requires consideration on this point.

The degree of friction necessary in the knee joint will be decided for each individual case as a result of experience, and will need alteration from time to time until the correct setting is found. The greater the friction, within limits, of course, the quicker the patient walks when once used to the leg; but in the early stages, and until the muscular strength of the stump has become re-developed, a primary amputation requires but little friction.

The examination of other types of limbs suitable for the ideal stump should be carried out with the same routine, but modified for the particular type of leg being examined.

Advice to the patient.—Instruction in walking is given in progressive stages, and the patient commences to walk between two hand-rails secured firmly to the ground. He is told to keep his shoulders back and head erect, and to look straight forwards and not down at the ground. The first pace should be taken with the sound leg, after which the stump should bring the artificial leg forward with the motion of kicking a football.

The usual tendency on the part of the learner is to take too long a stride at first and this must be discouraged. After some practice within the rails the patient should be encouraged to attempt walking outside the rails, with the aid of two walkingsticks and an attendant near at hand. As confidence is gained by this, aided by much encouragement from the attendant, one stick may be discarded and the patient will, in a few weeks, boldly walk unaided. Some patients practise for too long at a time, thereby tiring and causing cramp to the stump muscles, which, in this early stage, cannot tolerate much exertion. The patient should be encouraged to sit about, wearing the leg, and, at first, to walk on it only for a few minutes at a time.

Stump socks.—Each patient is given six stump socks and, whether wearing one or two socks when originally fitted, is instructed to add a sock if, and when, he finds he is coming down too hard on the ischial tuberosity, or that bone is slipping inside the lip of the socket. He is warned that he should not pack himself out of his socket by the addition of several socks for the purpose of alleviating pressure on a sore spot, but should report back to his limb-maker for adjustment. Much harm may be done to a stump by the incorrect use of stump socks, and cases

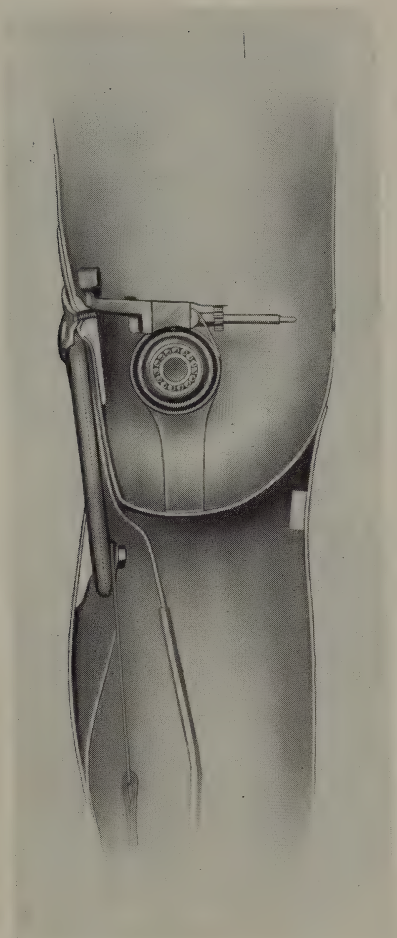

FIG. 1.—The Knee Piece.

Sectional view of knee showing details of ball-bearing Knee Joint and adjustable friction knee action.

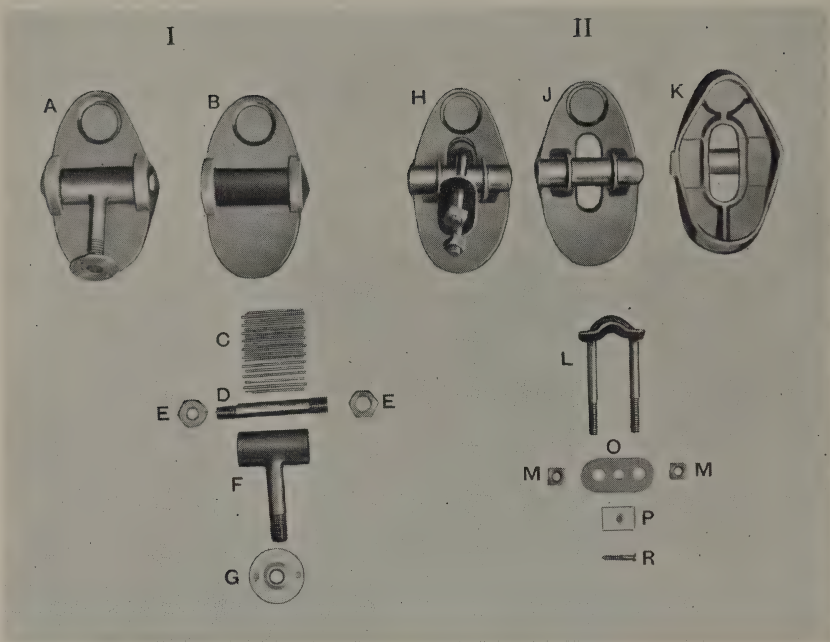

FIG. 2.

. Ankle Base and Joint.

A. Under surface of Base with Roller Bearing Joint assembled.

B. Under surface of base shewing recess for ankle joint.

C. Steel Rollers.

D. Ankle Bolt with retaining nuts " E "

F. Barrel with Single prong and " G " the conic nut.

II. Older Type Ankle Base with Staple Fittings.

H. Under surface of Base with joint assembled.

J. Under surface of base shewing ankle bolt.

K. Upper Surface of Base.

L. Ankle Staple with leather Bush.

M. Staple Nuts with " O " Staple Plate.

P. Locking Nut with " R " Screw.

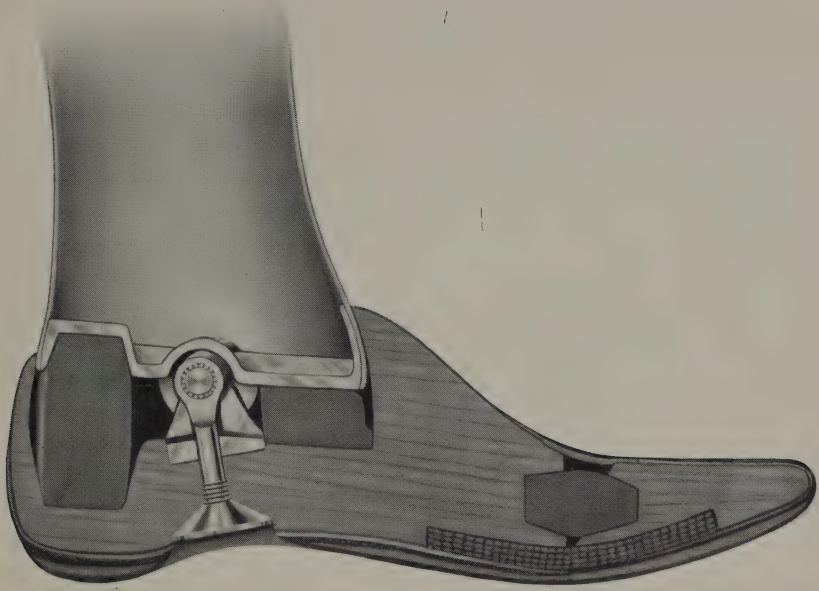

Fig. 3.—Wood Foot.

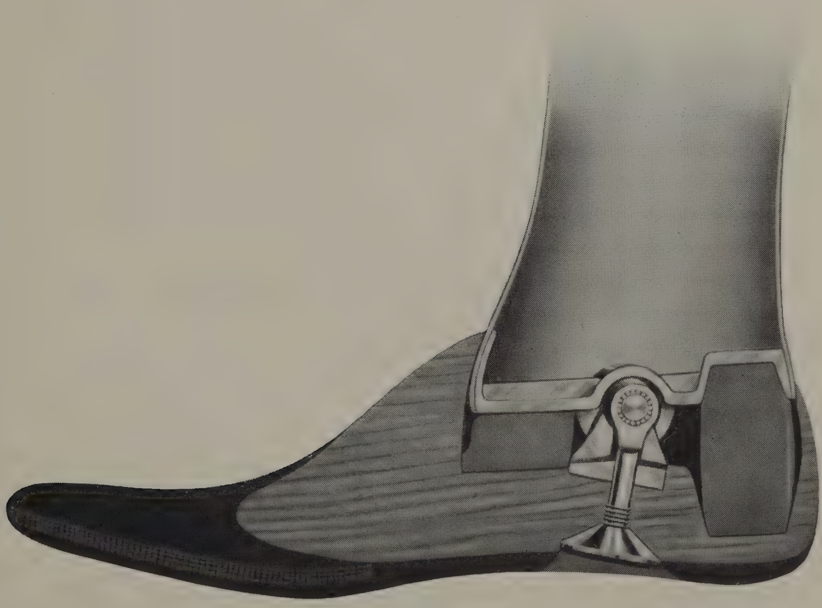

Fig. 4.—Rubber Foot.

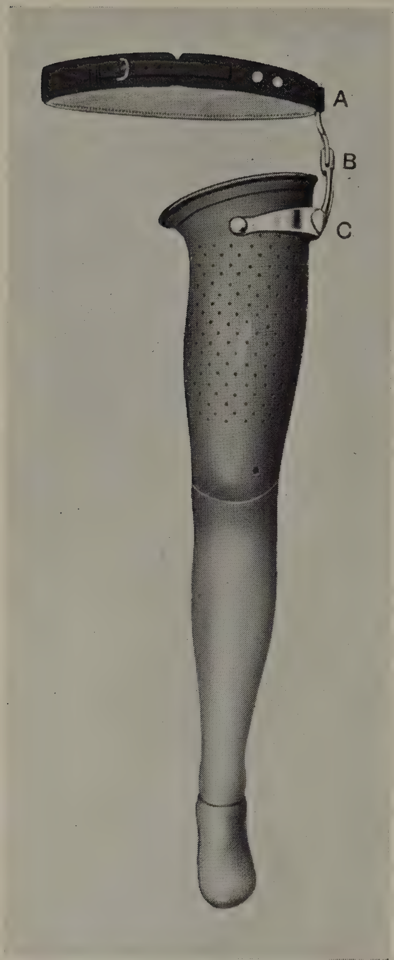

FIG. 5.—Leg with Double Swivel Pelvic Band.

A. Roller-bearing Rotation Joint.
B. Ball-bearing flexion and extension joint.
C. Stirrup with Joint for adduction and abduction.

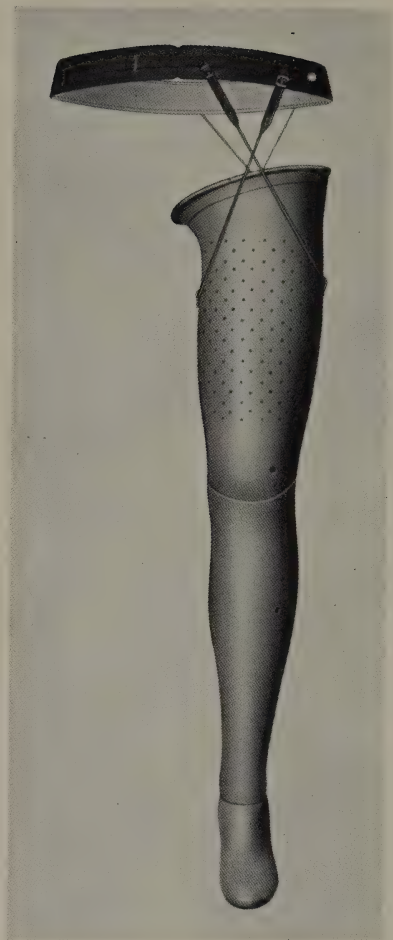

FIG. 6.—Leg with Compensating Pelvic Band.

have been seen where the patient has added three socks or more, thinking his socket was too big, whereas it was in fact much too small. Until a patient has become thoroughly accustomed to the use of a limb, and to dealing with minor stump changes, he should be advised to consult his Surgeon before experimenting on his own account.

The instructions on the washing of socks should be carefully observed, as careless washing and drying causes them to shrink. The patient should make sure that when a stump sock is put on it has no folds or rucks anywhere as they are apt to cause abrasion of the stump. The stump sock should be changed for a clean one every day, or more often if the patient perspires freely; the use of a sock hardened by perspiration can cause trouble to the stump.

A little talcum powder shaken on the stump and into the stump sock every day may be of advantage. Many favour the use of methylated spirit on the stump and use it regularly. Its use tends to keep the stump clean, but it is apt to dry up the skin, particularly in the neighbourhood of scar tissue, where some bland ointment is likely to be of more value and to keep the skin supple.

Faults in artificial limbs.—No attempt will be made to record all the defects which might arise in the use of a limb, but a few of the more common, and their cause and correction, are given below.

(1) *Height of the limb.*—Normally the length of the limb for a thigh amputation will be $\frac{1}{2}$ to $\frac{3}{4}$ of an inch short on the amputated side; this will have been determined by the fitter by trial during the fitting of the limb. If the limb is too short or too long, a postural scoliosis of the lumbar spine will be produced and cause complaints from the patient of vague lumbar pains, which are sometimes erroneously attributed to the unaccustomed use of the muscles in a primary case. It may be that the patient already had a scoliosis which was not sufficiently allowed for when the limb was made. If there is scoliosis when the patient is first fitted, the apparent shortening may be as much as two inches, but this may still be correct for that case.

If the patient lives in a hilly district, shortening more than usual will be required, and this is also necessary if the patient's occupation causes him to walk much over rough ground.

It is better that any error in height should be made in the direction of being too short rather than too long. Assistance in coming to a decision in any given case is provided by the use of the " walking shoe," a leather slipper after the style of an Arab sandal, fastened to the shoe by straps and buckles, and into which can be slipped insoles of known thicknesses. By this means the optimum height can be determined.

Some patients who complain that their legs are too long are found to have packed themselves out of their sockets by adding too many stump socks, possibly to relieve a sensitive spot. Some complain that the leg is too short, and on examination it is found that the stump has shrunk and they have failed to add the requisite number of socks to compensate for shrinkage; it frequently has to be pointed out to such patients that the artificial leg cannot grow or shrink.

(2) *Turning in or out of the toe of the artificial foot.*—If the patient is wearing a stump-controlled leg with double-swivel pelvic band, the incorrect " turn-out " of the toe is generally due to an error in the set of the male or female bearers of the hip joint, and the necessary adjustment can easily be effected at these points. It is possible, but very

rarely found, that the fault lies in the position in which the socket is set in the container, and a rotation in one or other direction may be necessary. No alteration to the foot or ankle is usually required to correct this fault. If such a complaint is made by a patient wearing a shoulder-controlled leg with central-knee-control, the error may be due to the incorrect positioning of the guide-loops upon the socket in front in such a way that more pull is exerted upon one roller cord than upon the other. When this happens the leg as a whole is rotated in or outwards.

It is possible that the error may be due to the patient's having put the limb on incorrectly and, through ignorance, he may be wearing it in a rotated position. A number of such cases have been noticed, but more commonly amongst women; this may be due to the more fleshy and flabby nature of the stump, which allows rotation to take place, and a pelvic band may be required to keep the limb in correct position.

(3) "*Knee-Shooting*".—A patient sometimes complains that the artificial knee tends to shoot forward, or flex, when weight is put on the limb, causing him to fall to the ground; this is referred to as "knee-shooting" amongst those who use artificial limbs.

A limb is designed with the knee-spindle slightly posterior to the middle of the knee, so that the centre of gravity falls in front of the joint: this is to give security against unexpected flexion of the knee, and the back-check ligament is set so that the thigh piece is vertical with the shin, with perhaps the slightest tendency to hyperextension at the knee. If any marked degree of hyperextension were allowed at the knee it would undoubtedly ensure that the knee never "shot," but the limb would be tiring to walk with and would be a "slow-walking" limb. The ligament is therefore adjusted to allow of but a small degree of hyperextension to ensure rapid walking, whilst safety against knee-shooting depends upon the degree of resistance exerted by the instep rubber in the foot. A normal degree of resistance is fitted whilst the leg is being made, but the patient may later complain of knee-shooting. This may be due to two main causes. Either the resistance is insufficient for the given case in the first instance, but not noticed until the wearer tries the leg over rough ground, or the instep rubber has perished. The fault can be corrected by the addition of a leather disc beneath the instep rubber or by fitting, in the latter case, a new rubber. The cause of knee-shooting will, therefore, be found by examining the foot rubbers. The back-check ligament is never set too short and cannot be held responsible.

(4) *Slow gait*.—Patients sometimes complain that the leg will not travel fast enough, and this, in a stump-controlled leg, will be found to be due to the shin, after flexion, not extending rapidly enough for the next pace; consequently the wearer has to wait for the shin to come forward. To accelerate extension of the shin, either an elastic pick-up of suitable strength or an internal knee-spring is fitted. Whichever is used, the knee friction must be balanced against it.

(5) *Leg tiring to use*.—It is occasionally found when a patient has had a leg in use for some time that he complains that it seems to tire him more than it did at first, and he cannot walk so far in comfort. On examination the first point to consider is the back-check ligament, which may be found to have stretched in use. The effect of this is that hyperextension of the knee joint has occurred, which renders it more difficult to flex the knee when walking. If, coupled with this, there is too much resistance in the instep rubber, the condition will be aggravated.

A more rare cause, but one that has been discovered in a number of

cases, is that insufficient flexion has been allowed when fitting the socket into the container. If the stump shows flexion when at rest and this has not been accommodated in fitting, in course of time the patient will feel that his stump is always being pressed backwards when standing erect, which may cause tension on the flexor muscles and lordosis of the spine. The symptoms may not arise till the leg has been worn for some time, but when the fault has been found, and corrected by giving the necessary degrees of flexion to the socket, the relief to the patient is immediately noticed.

6. SHORT ABOVE-KNEE STUMPS

In the preceding sections the stumps described have been called "ideal" and the artificial limbs referred to have been those suitable for ideal stumps. The way in which the metal "set-up" can be used to provide a limb suitable for stumps that cannot be regarded as ideal must now be considered. In general, if the stump is not ideal, a stump-controlled limb of the type already described will not be suitable, and therefore for these cases shoulder-controlled limbs are usually supplied. A stump may fail to be "ideal" in many respects, e.g., there may be a deficiency in length, a lack of muscle power, or some hyperæsthesia. Whatever the departure from the ideal, the effect on limb-fitting is the same, namely, that more support is required between the pelvis and the socket of the limb. A support, moreover, is not provided by the use of the full double-swivel pelvic band, which, in its original form, is merely used for purposes of suspension. The required support for a defective stump is given by the addition to the limb of either (1) a full rigid pelvic band, or (2) the pelvic band with a lateral abduction hip joint (Fig. 11.).

The full rigid pelvic band.—This type of pelvic band allows of no movements, except one of flexion and extension at the axis of the hip joint. The belt itself consists of a 2-inch wide stout leather outer cover, with a soft leather lining, and between these is fitted a piece of spring-steel. To the spring-steel is riveted the upper steel of the hip joint, the lower end of which articulates with the head of the lower steel in a ball-bearing joint. The lower steel is riveted to the socket of the limb.

When fitting this type of pelvic band the same rules apply as when any other type is being fitted, i.e., the lower steel of the hip joint is set at the junction of the anterior with the posterior two-thirds of the breadth of the great trochanter, and the centre screw of the joint is about ½″ lower than the highest point of the great trochanter. Great accuracy is required for the set of the joint, since, owing to the lack of movement in any direction other than flexion and extension, the wearer cannot accommodate himself to an incorrect setting.

The rigid pelvic band provides the most positive form of support obtainable and should give the wearer the impression of being held firmly in such a way that the limb feels part of him.

The pelvic band with a lateral abduction hip joint.—The belt is similar to that described above, except that there is incorporated in the hip joint a hinged joint which permits limited abduction and adduction of about 10° in addition to flexion and extension.

Length of stump.—An examination of some 3,000 cases of above-knee amputations showed that the average length of the ideal stumps requiring no pelvic-band support at all, and used with shoulder-controlled legs,

was $11\frac{1}{4}''$, the longest being $15\frac{1}{2}''$ and the shortest $8''$. Ideal stumps using stump-controlled legs with double-swivel pelvic band, for suspension only and not for support, averaged $10\frac{5}{8}''$ in length, the longest being $15\frac{1}{4}$ and the shortest $8''$. Non-ideal stumps requiring support by one of the types of band referred to above averaged $8\frac{3}{4}''$, the longest being $12''$ and the shortest $6\frac{1}{4}''$. Length alone therefore is not always the deciding factor in the selection of a pelvic band that gives support. The shortest stump requiring support measured $6\frac{1}{4}''$, and this indicated that a stump shorter than this cannot generally be fitted with an ordinary above-knee leg, but requires a tilting table, or special type of limb. Further than this it is impossible to dogmatize since so many other factors enter into the question.

A stump of less than $9''$ needs consideration for the supply of some form of pelvic band since the stump is not ideal in length, because the major portion of the insertion of the adductor muscles will be below the level of bone section and, therefore, the higher the amputation the less is the power of adduction. This deficiency hinders the patient from holding the leg underneath him and can be compensated by the addition of a rigid pelvic band, with or without a lateral abduction joint, according to the degree of weakness in this direction. For very short stumps the full rigid band will be essential; but, for slightly longer stumps, the lateral abduction joint is an advantage in that it reduces slightly that "trussed-up" feeling of which patients sometimes complain, and it will therefore be used for those who can control the limb with the slight increase of freedom it permits and who need the extra freedom for occupational reasons, and also for those who are constantly fracturing their pelvic-band steels, though the fracture is occasionally found to be due to incorrect fitting and setting of the hip joint.

Statistics show that the rigid pelvic band is also required for stumps as long as $12''$, due to the patient's being debilitated from long illness with resultant weakness of stump muscles, which makes it impossible to secure control of the leg without such support. As time goes on, however, and the general health improves, it is often found possible to give more freedom of movement, or even to dispense with the pelvic band.

The neurasthenic patient who has no confidence in himself, and, despite an ideal stump, would feel incapable of controlling the limb unaided by a pelvic band, must also be remembered. Elderly patients require support, though the stump may be normal, and patients who have been wearing for many years a full double-swivel pelvic band often find that increasing age demands an additional support, which can be given by modifying this type of band by making rigid either the rotation joint or the abduction joint. Certain cases whose stumps are short, but otherwise normal, can be fitted with a double-swivel band in the first instance, provided it is modified at one of these sites, but such cases are exceptions to the general rule.

Short stumps with limited movement.—It is sometimes necessary to provide a limb for a patient whose above-knee stump is short and either partially or completely ankylosed at the hip joint. If the stump is very short, i.e., under $6''$, a tilting-table limb—which will be described later (p. 38)—will in all probability be required, but otherwise the ordinary above-knee limb, with rigid pelvic band, must be adapted to suit the peculiarities of the case. Limbs made for such stumps are difficult both to construct and to fit, and success depends entirely upon the length of

stump, coupled with the degree of flexion at which the hip joint is ankylosed. Whatever the angle of flexion, the weight must be borne upon the ischial tuberosity, and the whole stump must be enclosed within the socket, the outer rim of which should be carried up to the level of the top of the great trochanter.

According to the degree of flexion present, the longitudinal axis of the socket will form an angle with that of the container and, the greater that angle, the more will the socket appear to be lying across the top of the container. The angularity formed at the junction of the socket with the container has to be modified by shaping the container in such a way that a gradual curve is produced on the anterior aspect, fading out to the vertical by the time the knee piece is reached. For example, a stump of 6″, with 15° of flexion, can be accommodated in a socket, and a container fitted, without much angularity resulting, and such protuberance as there is disappears at the point where the container meets the knee piece. If, however, the stump were 9″ long, with the same amount of flexion, there would be less room between the end of the stump and the lower end of the container to bring the latter back to the vertical. The forward prominence of the container would be very noticeable and, as the degree of flexion increases, the aesthetic effect gets worse until cases can occur in which the length of the stump and the degree of flexion prevent the container from being brought back to the vertical for insertion into the knee piece, and in such cases reamputation is indicated. When, for various reasons, a reamputation is undesirable, a limb can be constructed which is actually a modified tilting table. The socket is constructed as before, giving the required amount of flexion, and a pelvic band is fitted to it. An artificial hip joint is then fitted to the socket with steels running down from it on either side, and their lower extremities are riveted to the top of a straight container whose upper end only reaches to within about two inches of the bottom of the socket. This type, as illustrated (Fig. 10), is used for flexed stumps with complete bony ankylosis at the hip joint. The patient, without such a fitting giving an extra hip joint, would be unable to sit down (Fig. 10A).

It is impossible to describe every variety of case of this type that may arise, or to indicate the precise methods of fitting them, but the general principles to be adopted have been indicated.

The knee lock.—The functions of a normal ideal stump in using an artificial leg call for a certain amount of muscular control and exertion, particularly in maintaining the knee joint in the extended position when standing for long periods, and at each step in walking, and this exertion is more than many short stumps can reasonably be expected to sustain without some mechanical assistance. The required assistance is given by the addition of a knee-lock, which is operated by means of a long rod, lying along the thigh piece, the lower end of the rod engaging through the knee piece with a slot in the top of the shin. When the rod is pushed down the lock is engaged and flexion at the knee can no longer take place. The alignment of the knee-lock rod is such that the lower end will not engage in the slot of the shin until full pressure is applied to the instep of the artificial foot. The patient should be warned, therefore, that when he wishes to lock the knee he must lean a little forward, take all his weight on the forepart of the artificial foot, and then press down the rod. To disengage the lock, the same process must be gone through.

Knee locks are advised for many elderly primary-amputation cases;

for those who have little confidence in their ability to control the leg; and for patients with very short stumps, who would find it too tiring if they had to rely upon the stump alone in order to maintain extension at the knee. A lock is also necessary for most of the cases fitted with very flexed sockets for ankylosed hip joints. The need for the lock is thus due to the constant risk that the line of force of the body-weight might be directed behind the knee centre, and without a lock the knee would then "shoot" and the patient could not prevent it. Finally, a patient who has quite a good stump, with which he can control a limb well, may ask for a knee lock because his occupation involves prolonged standing, and another may require a knee lock because he lives in a very hilly district and finds going downhill a great strain. Such requests are reasonable, and knee locks should be supplied, with the advice not to get into the habit of using them unnecessarily if the patient wishes to maintain a good and normal gait.

7. VERY SHORT ABOVE-KNEE STUMPS AND THE TILTING-TABLE LIMB

In the best interests of the patient one of the limbs already described should be fitted, but, unfortunately, for many very short stumps this is not possible and they can be fitted only with the type of limb used for an excision at the hip-joint, known as the "tilting-table limb."

The tilting-table limb immobilises the very short stump but this is by no means a disadvantage for fitting, as the existence of some amount of stump permits a better fitting than is possible for an excision at the hip joint. As it is the heaviest and most cumbersome of all artificial limbs, it is never prescribed nowadays except as a metal limb (Fig. 12). The weight of a wooden limb for this amputation is excessive and the following remarks on the general principles of construction apply to the metal limb alone :—

The socket.—A plaster cast is taken of the stump and pelvis on the side of the amputation. If any femur has been left it should, if possible, be flexed at a right angle when the cast is taken. A male cast is then made to which the socket is moulded. Sockets for these limbs may be constructed of different materials such as leather, certalmid, and metal.

The leather socket is made from very stout material which is blocked to the cast, lined inside with a thinner and softer leather, and fitted with a leather-covered sponge-rubber pad over the area corresponding to the ischial tuberosity. The certalmid socket is fashioned in the same manner from a number of layers of butter muslin, suitably treated with a special glue, which gives a smooth shiny surface on inner and outer aspects. It retains its shape only fairly well and can be perforated to a certain extent for ventilation purposes. The leather-covered sponge-rubber pad is fitted as in the leather socket.

The metal socket has the advantage that it can be perforated all over with $\frac{1}{8}$ in. holes without loss of strength, and it is also fitted with the sponge-rubber pad under the ischial tuberosity. Advantages are, however, claimed for all three materials and doubt may arise in deciding the most suitable for any given case. The leather socket, being unventilated, is the heaviest and hottest, but many patients think it is more comfortable. The certalmid socket is very much lighter and therefore cooler, but tends to lose its shape in time and is adversely affected by perspiration. The metal socket is as light as, if not lighter than, the

certalmid socket, is well ventilated and strong, and suffers little from corrosion now that "alclad" is used. When first introduced it was not received very favourably by patients who thought it might be too hard for the stump and tissues of the pelvis, but experience has disproved this idea. It may be that, for patients whose pelvis is very poorly covered and has prominent bony points, the leather socket would be better, but, with this exception, the metal socket seems eminently suitable, particularly for those who need the lightest possible limb.

The socket, of whatever material it may be constructed, is supported by a skeleton framework of steel. On the outer side will be seen a Y-shaped steel which is riveted to the socket in such a way that the lower extremity projects below the level of the socket and forms, with the lower and outer female steel, the outer hip-joint. On the inner aspect the socket is reinforced by a steel which follows the inner edge,and, in the region of the ischial tuberosity, this part of the steel is further reinforced by the addition of another, stouter, steel called the "Tuber Plate". The inner male steel is riveted to the tuber plate and projecting downwards goes to form the inner hip joint by articulation with the inner female steel.

The socket with its metal framework is mounted upon a metal thigh-portion which resembles the container of an ordinary above-knee limb, except that it is flattened posteriorly.

The lower, or female, steels that go to form the hip joints are riveted to the top lateral aspects of the thigh portion; they are reinforced by means of a distance-piece which gives rigidity. The lower extremity of the thigh portion is riveted to a knee piece of the type usual to above-knee metal limbs, and the remainder of the tilting-table leg is exactly as already described under the "set-up" of above-knee metal legs.

The hip lock.—When the limb is constructed, as briefly described above, the patient is able to sit down, since the hip joints allow the thigh portion to flex to the required angle on the socket, but if the patient stands, he has no means of maintaining the socket and leg in the erect position for there is no stump fit to control a leg. To overcome this, a hip lock is fitted to the outer female steel. It is held by a spring. To release the lock, and for sitting down, the patient presses a button on the female steel, but when he stands erect the lock engages automatically and holds the socket and thigh piece in the erect position.

Methods of suspension and control.—Suspension by means of webbing suspenders over the shoulders is necessary for all tilting-table limbs, and, as there is no stump control, as close a connection as possible between the shoulders and the moving parts of the limb must be arranged. This is commonly provided by means of the central-knee control, which is the most positive form of control available.

Some patients, however, use double suspenders which are attached to the socket only, excessive movement of the shin on the knee being prevented by means of a wide elastic from the top front of the shin to the top of the container or the socket.

The knee lock.—Occasionally it is found that the patient using a tilting-table limb feels very insecure when walking, owing to the risk of knee-shooting, and it may be necessary to add a knee lock on this account.

The fitting of the tilting-table socket.—The comfort and security afforded to the wearer of a tilting-table limb depend almost entirely upon two interconnected factors: (*a*) the site of amputation and (*b*) the

ability of the fitter to make a maximum use of any bony prominences on the pelvis, such as the anterior superior spine. The socket is carried up on the pelvis to just below the iliac crest and it must be fitted in such a manner that it is felt as a part of the wearer, with no tendency to rotate or to fall away as the patient swings and rotates his pelvis to take a forward pace. When it is appreciated that the movements obtainable with this type of limb are those induced by a swing of the pelvis, it will be realised that the position of the socket, and therefore the leg on the stump, must remain constant in all movements, failing which there is a feeling of insecurity and added weight.

If an excision at the hip joint has been performed, the resultant stump presents no prominences either laterally or anteriorly and, no matter how accurately the socket be fitted, it cannot be held securely to the pelvis without tight strapping of the pelvic band and, probably, the addition of a further pelvic strap fitted just beneath the usual pelvic band. There is always an impression that the socket and limb might slip off. If, however, head and neck of the femur have been retained, the stump, when viewed from the front, will show a prominence laterally that is of the greatest value to the fitter, inasmuch as the socket when accurately moulded around the prominence thus formed is more securely anchored.

If the head, neck, great trochanter, and a portion of the shaft of the femur are left, a small stump is formed which is held flexed at 90 degrees when the cast is taken. This produces a prominence anteriorly, around which the socket is moulded, and provides an additional anchorage for the socket.

From the point of view of limb-fitting and limb-wearing the best possible stump with which to fit a tilting-table leg is one that has been amputated at the level of the lesser trochanter, and this site is advised, whenever surgical conditions permit, rather than a shorter stump or an excision. The average length of stump (where any stump is present) that is fitted with a tilting-table measures $4\frac{3}{4}$ inches from the tip of the great trochanter.

The fitter, having moulded the socket so as to take every advantage of the natural angles provided by a small stump, will arrange that the ischial tuberosity rests upon a sponge-rubber tuber pad lying on the tuber border of the socket in such a way that the edge of the tuber margin of the socket is in the same vertical plane with the medial border of the ichial tuberosity.

If the tuberosity rests too far within the socket the leg will tend to adduct, and the perineum will be chafed, whilst, if it lies unsupported by the tuber margin of the socket, the leg will abduct and damage the stump.

Indications for prescribing a tilting-table leg.—If a patient has had an excision at the hip joint, or an amputation through the femoral neck, undoubtedly the only suitable type of limb is the tilting-table, but if the stump is slightly longer a tilting-table leg should, if possible, be excluded, since no patient should needlessly be condemned to wear this limb. It is not always easy to decide whether a given case can or cannot wear a modified form of the limb suitable for the ideal thigh amputation, and the decision is made no easier by the knowledge that, if it is wrong, great physical strain and unnecessary expense will result to the patient. Experimentation, moreover, is equally costly and therefore affords no assistance. The points that should receive consideration are as follows :—

(1) *Length and nature of stump.*—The length of the stump alone is not the deciding factor; the conformation of the stump must also be con-

sidered. For example, a stump of 6 inches from the tip of the trochanter, giving a fitting-length of about $3\frac{1}{2}$ to 4 inches from the perineum, will not necessarily be suitable for a modified above-knee leg, but its general shape must be considered before deciding to fit a tilting-table leg. Other things being equal, it should be possible to fit a stump of that length, if muscular, with an above-knee leg, but, if the stump is fat and flabby, it may well be impossible to retain it in the socket of an above-knee leg, and the tilting-table leg will be the only alternative.

(2) *Condition of stump.*—A stump may be of sufficient length and suitable shape for an above-knee leg, but unsuitable owing to the presence of painful scars near the ischial tuberosity, or on the anterior aspect; or there may be a painful nerve which cannot be removed without adding further scar tissue in the place where it is least wanted. For such cases the tilting-table leg may be required.

(3) *The tilting-table leg or a tilting-table peg?*—When it has been decided that nothing but a tilting-table limb will suit a given case the next point for consideration is the precise nature of the limb to be given. Those for whom a tilting-table limb is necessary are frequently debilitated, and in a very weak state from long illness and the shock of the high amputation, and it is at times questionable whether the patient will be able to manage with a limb weighing as much as a fully articulated tilting-table. It is also usually desirable for his general health that the patient should be able to get out in the open air, and to take some graduated exercise, with as little strain to himself as possible, but the weight of a full tilting-table limb may prevent the patient's using it without undue tiredness. For such cases the tilting-table peg leg is of great advantage, and may save the patient from using a chair for the rest of his life. Few patients, however, take kindly at first to the idea of a peg leg and there is disappointment that a leg with a foot is not suggested at once. It should then be explained that the peg is prescribed only until the general health and strength have improved sufficiently to enable the full tilting-table leg to be used without undue fatigue. A number of cases have been dealt with in this manner and it has been found possible, after about a year's use of the peg, to fit the fully articulated leg without any harmful results.

The peg leg for this amputation is about $1\frac{1}{2}$ lbs. lighter than the fully articulated leg and, in addition, there is a saving of the weight of the boot or shoe which the patient would otherwise have worn. The construction of the peg leg is exactly the same as that of the fully articulated leg so far as the socket and thigh piece are concerned; the only difference is that a metal tubular peg, with suitable peg-end of rubber or uskide, is fitted to the knee-piece, in lieu of the shin and foot. A knee-lock holds the knee in extension when the patient stands up and walks.

Examination of the tilting-table leg.—The routine method of examining a new leg is similar to that used with an ordinary above-knee limb, but some special points require attention—

(1) *The socket.*—The socket should fit closely to the stump and pelvis and it should be impossible to insert the fingers between the top edge of the socket and the pelvis at any point. It should be built over the prominences of the great trochanter and stump extremity, if present, so that there is no movement between the socket and the pelvis.

(2) *The ischial tuberosity* should rest on the lip of the socket so that

the medial plane of that bone is in the same plane as a line drawn vertically upwards from the tuber edge of the socket.

(3) *The height of the limb* should permit of reasonable ground clearance when walking, and it should be appreciated that as the wearer when walking is unable to flex the artificial knee to the same extent as does a patient wearing an above-knee limb, the artificial limb will be a little shorter than is usual with ordinary above-knee limbs.

(4) *Movement in walking.*—When the patient walks, the leg will be swung forwards by a slight rotary movement of the pelvis, but the leg should not rotate or abduct.

(5) *Position in sitting.*—When sitting, the thigh portion of the limb should set square on the chair, and there should be no tendency for the thigh portion and the knee to rotate.

(6) *Hip and knee locks.*—It is very necessary that the patient should be able to use the hip- and knee-locks properly before he takes the limb into use.

8. LONG ABOVE-KNEE STUMPS — TRANSCONDYLAR AMPUTATIONS AND DISARTICULATION AT THE KNEE

General disadvantages of long above-knee stumps.—At one time the general practice in amputation was to retain as much bone as possible and the level of bone section was determined by surgical conditions alone. Little was known of the limb-bearing capacity of stumps until the Great War provided experience on an increased scale that modified former opinions. To-day it is axiomatic that, whilst a good surgical result is not always good prosthetically, a good prosthetic result must of necessity be a good surgical result. When it was first suggested to the surgeons concerned with stump surgery that above-knee amputations might well be shorter than appeared desirable from the purely surgical point of view, the reply was that they were being asked to produce stumps to fit the artificial legs, whereas artificial legs should be made to fit the stumps. But when it became evident that the shorter stump gave less trouble, surgical opinion changed, and it is now most unusual to see a long above-knee stump sent for limb fitting. Muirhead Little (writing in 1922) stated* that of 441 above-knee stumps 135 measured over 12 inches, of which 87 were more than 13 inches. Nowadays, a stump over 13 inches might be regarded as an accident.

Apart from the alleged value of the greater leverage given by the long stump, the taking of weight on a pad fitted in the socket below the stump end used to be thought an important point in favour of the long stump. It is felt now that this was making a virtue of necessity, since the limb-maker had no other alternative but to fit an end-bearing for many long stumps, particularly those amputated through the condyles of the femur, and the percentage of long-stump cases fitted with end-bearing was very high, whereas end-bearing is now rarely fitted. There are also surgical objections to the long stump for, sooner or later, the circulation at the stump extremity becomes defective. The early signs of this are a slightly more pinky tinge of the skin over the last few inches, and increased warmth in this area. At this stage no other symptoms may arise, but later the patient complains of throbbing in the stump end,

* Op. cit. (p. 15).

which becomes progressively more red and swollen, with painful sensations, noticed most when the limb is removed at the end of the day. Eventually, the stump-end becomes purplish in colour and is cold to the touch; there is a persistent dull aching pain; and small ulcers will appear which may eventually coalesce. At any time during these stages the need for relief of symptoms may render reamputation necessary; and it is then frequently necessary to make the bone the section at a level considerably higher than would have been required had it originally been made at the ideal site. The patient with a long stump is therefore liable to reamputation, with all the preceding pain and discomfort, and is eventually left with a stump that may be too short Though there is no proof that the use of end-bearing with these long stumps expedites the deterioration of the stump-end, there is a strong suggestion that it does, since, in some cases, the removal of end-bearing and the fitting of the patient on the ischial tuberosity have for a time retarded the process of deterioration, though reamputation has ultimately become inevitable.

These remarks apply to all long above-knee stumps in which the bone-section has been made through the shaft, or through any portion of the condyles, but do not apply in the same degree to disarticulations at the knee. Disarticulations at the knee provide stumps that have a considerably longer life and can tolerate longer some end-bearing, but the ultimate result is usually the same, though more distant. Disarticulation at the knee is not normally performed, for reasons which will appear later, but, in some cases, fortunately very rare, there is no other alternative, e.g. the patient whose extensive scarring in the upper end of the thigh, or some other condition, entirely precludes an ischial bearing. The once popular Stokes-Gritti operation is not now performed as it has proved, generally speaking, a failure, for the reasons already given, and most of the stumps resulting from it have long since been reamputated.

The site below which bone-section should not be made is 4 inches above the adductor tubercle in a man of average height, though, if the patient is very tall, this gives too long a stump; yet, if this method of measuring is taken in conjunction with that of 10 to 12 inches from the tip of the great trochanter, a stump of satisfactory length should result. It is extremely rare to find an above-knee stump of the ideal length suffering from circulatory disturbance at the extremity, even after 20 years; if such a case arises the trouble will probably be due to continuous wearing of a limb that no longer fits, with resultant pressure in the adductor region.

Mechanical difficulties with the long above-knee stump.—If a stump is longer than the ideal, its length often makes the ideal type of limb unsuitable and a second-best has to be provided, with which the patient cannot walk so well, and which may not be so good for the stump. In deciding on the second-best the extent of clearance between the end of the stump, when dependent, and the centre-line of the natural knee-joint in the horizontal plane must first be determined, since it is within that space that the knee-mechanism of an artificial limb is fitted so that the stump-end does not abut upon it, and allowance must also be made for piston action usually occupying an inch of that space. It is necessary therefore, to calculate the height of the standard adjustable knee-brake, above the centre of the knee-spindle to which one inch for piston action must be added, before it is possible to certify that a patient can be given a stump-controlled leg; the vertical space occupied by the central-knee-control bracket and pulley must also be

ascertained if a central-knee-control mechanism is desired. It is true that if there is insufficient clearance between the stump end and the knee-spindle for the addition of the central-knee-control bracket and pulley, a somewhat similar action can be produced by using Moore's outside control, but this is not such a good control. If it is very necessary to fit either a stump-controlled leg, or a central-knee-controlled leg, and the lack of clearance for either of these is wanting by only about half an inch, having allowed for the one-inch of piston action, it is possible to drop the knee centre by lengthening the thigh portion and shortening the shin proportionately. This action, however, gives a thigh piece which, when the patient sits down, projects in front of the natural knee and, to many, is very objectionable.

The actual vertical space occupied in the knee piece by the various fittings commonly used are as follows:—radius of knee-spindle with distance piece—$\frac{1}{4}$ inch; dead centre of spindle to top of standard adjustable knee-brake attachment—$1\frac{1}{4}$ inches; dead centre of spindle to top of central-knee-control bracket—1 inch; dead centre of spindle to top of internal knee-spring—$1\frac{1}{4}$ inches. Adding one inch, on the average, for piston action, the clearance required for a stump-controlled leg is $2\frac{1}{4}$ inches at the minimum, and it would be safer to allow $2\frac{1}{2}$ inches. For central-knee-control the minimum is 2 inches, and $2\frac{1}{4}$ inches should be allowed. Since $2\frac{1}{4}$ inches above the extremity of the condyle of an average femur is at a level above the condyle, it follows that a trans-condylar amputation cannot be fitted with an ideal stump-controlled, or central-knee controlled leg, though it might be fitted with the spindle in the knee piece only, and three- or four-point suspension.

The through-knee limb.—When there is insufficient clearance for a knee spindle without dropping the knee centre by lengthening the thigh piece, and the patient objects on æsthetic grounds, the only alternative is to supply the type of limb originally designed and constructed for disarticulation at the knee joint, i.e. the through-knee limb (Fig. 13.). The most distinctive feature of the through-knee limb is the socket, which is constructed of heavily blocked leather. Leather must be used for this type of stump since, if the condyles are included, the stump will be greater in diameter at the end than higher up, in which case the bulbous end could not pass down through the narrow part of the socket if it were not constructed to make allowance for this condition. A cast is taken of the stump, and from this female cast a male cast is made to which, when suitably built up as required, the leather is blocked and shaped when wet.

The socket is slit up anteriorly from about two inches above the extremity, either to the top, or to within four inches of the top, and, where slit, an eyeleted lacing section is made. The socket is unlaced to allow the stump to go through and then laced up firmly when the stump is in position. The upper portion of the socket is shaped like that of an ordinary above-knee leg, having a tuber and a gluteal shelf upon which the patient may take his weight entirely if it is desired that none should be borne upon the stump extremity. In the closed end of the socket a leather-covered sponge-rubber pad is fitted, upon which the stump rests if end-bearing is taken, as it sometimes is if the stump is the result of a disarticulation at the knee, but not otherwise. Theoretically, some weight may be taken at the top of the socket, and some on the end-bearing pad; most should be taken at the top; but it is impossible to assess the precise distribution of weight and an ischial bearing should be

given, the end-bearing pad coming into use only when piston action takes place. The socket is mounted upon long steels riveted laterally, which, at their lower extremities, articulate with steels attached to the upper end of the shin to form knee joints which work in ball-bearings.

Hyperextension at the knee is prevented by means of a Keegan back-check consisting of a leather strap, doubled on itself, which passes through an upper back-check holder, riveted to the upper side-steels, to be attached to a lower back-check holder, riveted to the top of the shin at the back. The top of the shin is low at the back to permit of full flexion and, except for this, the rest of the shin, ankle, and foot are as described under the metal "set-up".

The limb is suspended by means of a Y-shaped leather strap, the Y being inverted, each arm being attached to studs upon the top front of the shin. The upper end of the strap is attached to the anterior part of the suspenders worn over the shoulders, whilst the posterior part of the suspenders is attached to a back lift, which consists of a piece of 2 in. wide elastic with leather tabs at each end, the lower tab being attached behind by a leather thong to the top of the socket.

The main objections to the through-knee limb are the leather socket, and the fact that the action of the leg cannot be controlled in the best manner by the stump's action, since no mechanism can be fitted within the knee portion. The limb is heavy and hot to wear, and it may well be that the heat and lack of ventilation cause deterioration of stumps.

9. AMPUTATIONS BELOW THE KNEE

The ideal below-knee stump.—In the same way as there is only one particular above-knee amputation which provides what might be termed a perfect stump, there is only one below-knee amputation which can give lasting satisfaction.

The below-knee stump is measured from the inner articular surface of the tibia to the end of the bone when the knee is flexed; about six inches is regarded as the ideal length, and the fibula should be one inch shorter than the tibia. From the limb-fitting point of view an anterior flap would be preferable, since the resultant scar would be transverse, posterior, and well above the cut extremity of the tibia, but it is, nevertheless, inadvisable, as it would be poorly nourished. A short posterior flap, giving a scar which is transverse, terminal, and in the anterior portion of the stump's extremity but not encroaching upon the anterior aspect of the stump, gives a stump that appears to fulfil satisfactorily all its necessary functions. Various other flaps that appear to produce a good stump can, and in some cases must of necessity, be provided, and the only method now definitely contra-indicated is the equilateral flap, which does not provide a good stump because the resultant scar is antero-posterior, in which position it is subjected to piston action in the socket, which puts tension on the scar and causes it to split. In addition, the scar eventually becomes drawn up between the ends of the tibia and fibula and is sulcated. When this occurs the stump end becomes unhealthy, leading to the formation of intertrigo, inflammation of the surrounding tibia, ulceration, and subsequent re-amputation.

There are arguments for and against excision of the fibula at the time of amputation. Excision produces a clean conical stump, and the bursa, which so commonly appears over the head of the fibula, is avoided; but tibial bearing cannot be given to a stump for some six months after the amputation, and frequently cannot be given at all, owing to the

location of the scar on an area intended for weight-bearing. In most cases, therefore, excision means that ischial bearing is essential.

The presence of a bursa over the head of the fibula is not a contra-indication to tibial bearing, provided it remains healthy and of reasonable size, for it can act as a natural protection to the part, and usually gives no trouble in properly fitted cases. Excision certainly gives a clean conical stump, but the retention of the head of the fibula, although it makes fitting a little more difficult, nevertheless gives an anchor which prevents any tendency of the socket to rotate on the stump in walking.

From the limb-fitting point of view, therefore, excision of the fibula is not recommended, except in very short stumps where the lower end of the fibula becomes abducted and interferes with fitting.

A stump longer than seven inches, measured from the inner articular head of the tibia, falls within the category of long stumps. Fortunately for the amputee, it is increasingly recognised that the long below-knee stump has not only no advantages but, in fact, real surgical as well as mechanical disadvantages. The lower part of the leg is poorly supplied with blood and any amputation in that area must produce a stump that will, sooner or later, suffer from defective circulation. The great majority of long stumps resulting from the Great War have been re-amputated.

The treatment of the stump after amputation can be summed up as rest and absence of interference; nothing else is needed save the avoidance of any flexion deformity. When the stump is soundly healed and free from pain, a crêpe bandage may be advantageous, provided it is applied firmly from the bottom of the stump in an upward direction, the tension slackening off as the bandage is carried upwards. To keep the bandage in position a stump sock may be worn over it. The patient should be encouraged to commence active movements of the stump and knee joint, but, in most cases, passive movements and massage are neither necessary nor advisable. In a normal, uncomplicated, case the stump will be ready for the fitting of a permanent limb in two to two and a half months from the date of amputation; that is, it will be soundly healed, collateral circulation will be established to the extent that œdema has disappeared from the extremity, and it will permit of reasonably firm handling, indicating that the nerves have settled down.

When the stump is ready for fitting with a limb it is necessary to decide whether a permanent limb should be given at once, or whether a plaster pylon is necessary to shrink the stump down. In most cases the correct use of a crêpe bandage will do all that is required in shrinking a stump, and, for below-knee stumps, every effort is made to avoid the use of a plaster pylon, which should be limited to those cases in which the stump is uniformly swollen. It is sometimes found that the circumference of the stump at its extremity is greater than that at the level of the tubercle of the tibia, and a pylon will then only do harm to the stump. In such a case the crêpe bandage may not have been applied with sufficient pressure below; or, if it has been correctly used and has failed to reduce the swollen extremity of the stump, then massage may be given to supplement the action of the bandage.

The fitting of the below-knee stump.—A patient with a below-knee amputation may be fitted with an artificial leg so that he takes his weight either on his ischial tuberosity or on what are called the tibial bearing surfaces. These bearing surfaces are the anterior tubercle of the tibia and the ligamentum patellae and the inner head of the tibia. The area

just below the head of the fibula can also take some pressure. Conflicting opinions are held on these two methods. Some advocate nothing but ischial bearing for all below-knee stumps, whilst others, though admitting the value of such a fitting, do not apply it to all cases. On this question of ischial or tibial bearing, it may be argued that the bones just below the knee are not well adapted to take pressure, but experience shows that when the socket of the artificial limb has been carefully fitted the stump will remain in good condition for many years. Tibial bearing has, in most cases, been tolerated for about fifteen years, and it is only during the past seven years that it has been found necessary to convert some of the Great-War cases to ischial bearing. If, however, there is any doubt in the first instance on the ability of the stump to tolerate tibial bearing, the case is fitted with full ischial bearing.

Statistics, based on some hundreds of stumps of all types, good, bad and indifferent, show that since 1930 there has been a progressive increase in the proportion of ischial-bearing, in both wooden and metal limbs, from about 1 in 4 in 1930 to 1 in 2 in 1938. The majority of the cases included in these figures have for many years used tibial bearing, but can, or should, no longer do so. (Some were recent primary amputations on patients who for years have suffered from chronic sinuses, sciatic nerve lesions, etc., whose stumps were never ideal, and who would in any case be fitted with ischial bearing.) If, then, it is known that, after some years of tibial bearing, ischial bearing will have to be substituted, why should tibial bearing be used for any below-knee stump? The answer lies in the greater range of mobility and activity allowed by tibial bearing, compared with ischial bearing, in which the weight of the limb is increased and there is a definite restriction of movement. The fitting of a long ischial-bearing corset resembles the fitting for an above-knee amputation in limiting the freedom and naturalness of the gait. Bending sideways and stooping are also limited, whilst climbing of hills, stairs and ladders is made almost as difficult as in the case of an above-knee amputation.

It is often very difficult to persuade a patient who has once had tibial bearing to be fitted in any other manner, and many would rather continue with a painful stump than have an ischial bearing. Some, moreover, have had to give up their previous occupations on account of the limitation of movement produced by the change to ischial bearing. On account of these reasonable complaints, in some cases, when the stump-condition has not been too serious, the ischial-bearing corset has been cut down by about two inches, so that the patient takes a thigh-bearing instead, which relieves much of the weight from the stump. It is, however, dependent upon a tight lacing of the corset which invariably leads to atrophy of the thigh muscles, and, though many patients continue with this method for a considerable time without apparent harm, others are soon forced to give it up owing to stump congestion, and to return to true ischial bearing, even at the risk of losing their employment. Ischial bearing is therefore not prescribed as a routine for those who have previously used tibial bearing, despite the fact that at some future date such a fitting may be required. For primary below-knee amputation cases, if the stump is not in all respects perfect, the question of tibial bearing will not arise, but, if the stump is perfect, decision must be made between tibial and ischial bearing.

If the tibial epiphysis has not joined, tibial bearing gives a risk of separation owing to a hyperextension at the knee-joint, and several such cases have been observed in young children. This risk is eliminated by the use of ischial bearing. Between the ages of about 25 and 45 it is, for

occupational and other reasons, most important that there should be a maximum freedom of movement, and, if the stump of a patient within that age-period be sound in all respects, and it is known that a possible twenty years of comfortable and free limb-wearing can be anticipated, then he should be given the benefit of the extra freedom provided by tibial bearing. For patients over the age of 45 it is usual to supply ischial bearing, since for them great mobility is not so important; but there are, of course, exceptions.

Cases not suitable for ischial bearing.—The use of ischial bearing for below-knee stumps is contra-indicated by :—

(1) severe scarring of the thigh in the neighbourhood of the ischial tuberosity; or

(2) a flexion deformity of the hip-joint on the amputated side for mechanical reasons, on account of the altered direction of force, a flexed thigh cannot be fitted with true ischial bearing.

The position of the artificial knee joint.—The correct setting of the artificial knee joint plays a most important part in the comfort of the stump.

The difficulties experienced in fitting the artificial joint are due to the fact that, whilst the artificial joint has, until recently, been a fixed-axis joint, the natural knee joint has no fixed axis, its movements being a combination of flexion and extension with a sliding movement, and it is not mechanically possible, with a fixed-axis joint, to reproduce accurately the movement of the natural knee joint. Until a few years ago the fixed-axis joint was the only type used for below-knee amputations, and it had to be set in what had been decided was the optimum position, interfering least with the normal range of movement of the natural joint. This position is obtained by setting the artificial joints on the socket of the limb in such a way that the centre of the main screw of the joint is in the vertical plane of the level of the upper insertion of the crucial and lateral ligaments, or the level of the mid-patella line, whilst, in the horizontal plane, the centre of the screw should be set at the junction of the anterior three quarters with the posterior quarter of the knee. If the joint is set forward of this position the anterior tubercle of the tibia ceases to take a bearing on the socket in flexion, and the tissues at the back of the stump become compressed. If the joints are set too far back the opposite occurs. The optimum position, however, makes no allowance for the sliding movement in the natural knee joint and, since this sliding action must occur, it follows that it does so in mechanical conflict with the fixed joint, with varying degrees of friction to the stump. Bursae, thought to be due to pressure, have been shewn to be caused not by pressure, but by friction, and have disappeared on removal of the causes of friction, though the pressure still remains.

The fixed-axis joint also materially reduces the flexion available at the knee joint, and many patients with fat stumps complain that they are unable to flex the knee to more than a right angle.

The polycentric knee-joint.—Various designs have been tried to overcome the objections to the fixed-axis type of joint and the first attempt at a polycentric joint appears to have been introduced on the Continent by Martin Loth.

In this country, the Hanger polycentric joint has been designed and its results observed in 50 cases. It consists of an upper and a lower steel with

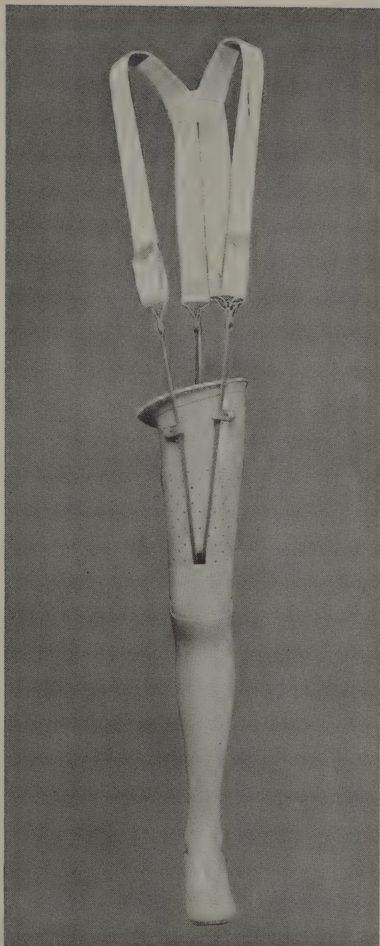

Fig. 7.—The Central Knee Controlled Limb. Shewing the Roller Cords, Guide Loops and Suspenders.

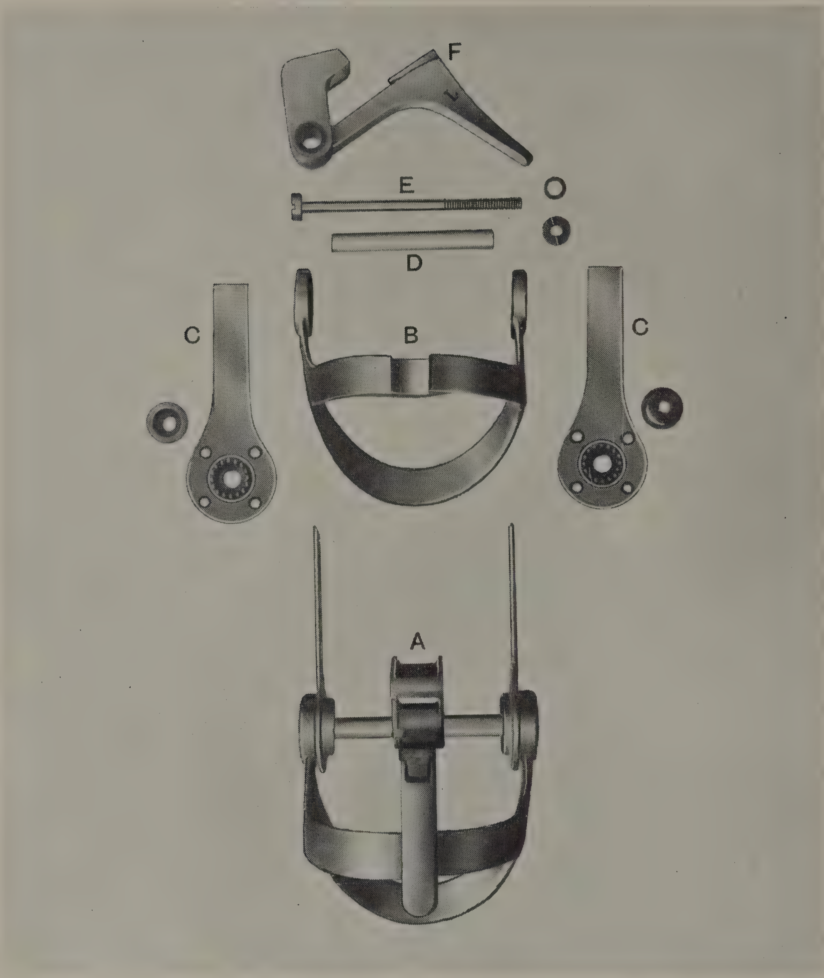

FIG. 8.—Knee mechanism of the Central Knee Controlled Leg (1933 Type).

A. The unit assembled.

B. The Chassis or Knee Cage which fits into the top of the shin.

C. Housings to accommodate ball bearings fitted within Knee Piece.

D. Distance Piece which passes over "E" the Knee Bolt.

F. The Central Knee Control Bracket.

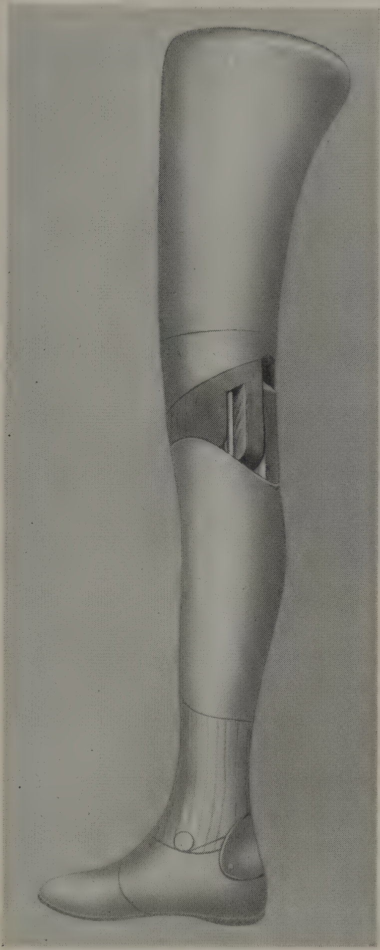

FIG. 9.—Anglesey limb for above knee amputation.

FIG. 10 Metal Limb for short thigh stump ankylosed at the hip. For sitting position see FIG. 10A.

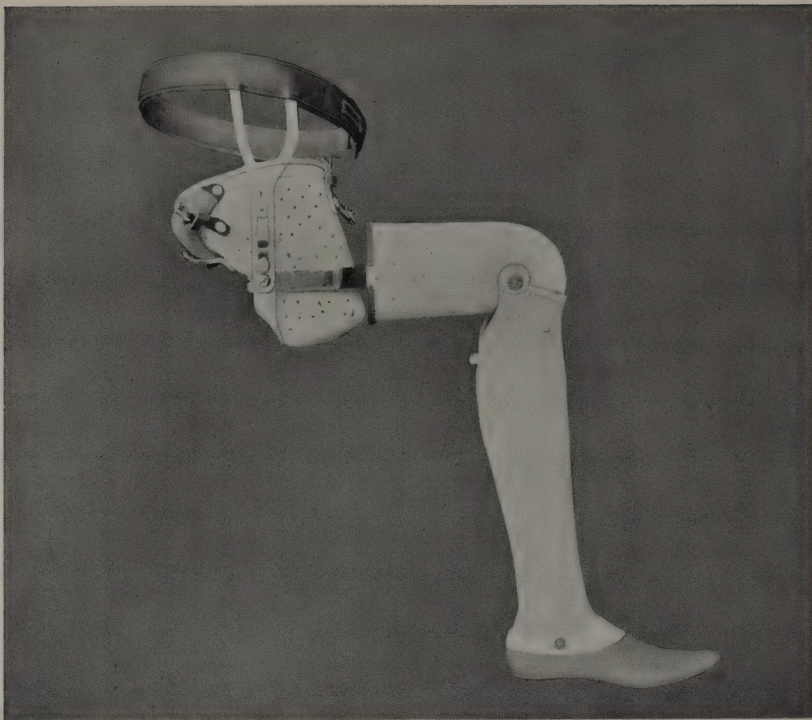

FIG. 10A.—Metal Limb for short thigh stump ankylosed at the hip, indicating the manner in which the thigh portion of the limb is allowed to flex forwards upon the socket when the patient sits down.

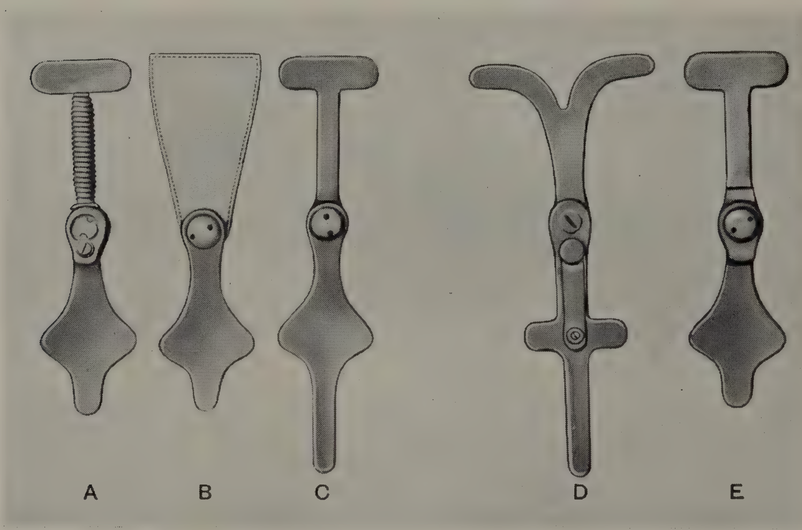

FIG. 11.—Some Types of Hip Joint.

A. Spiral coiled spring.
B. Hip Joint with Leather upper member.
C. Rigid Hip Joint allowing for flexion and extension only.
D. Rigid Hip Joint with spring locking device.
E. Lateral Abduction Joint.

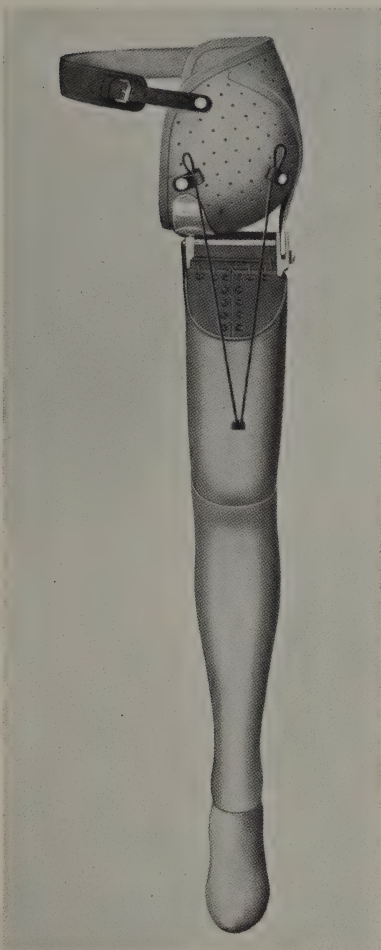

Fig. 12.—The Tilting Table Limb with metal socket.

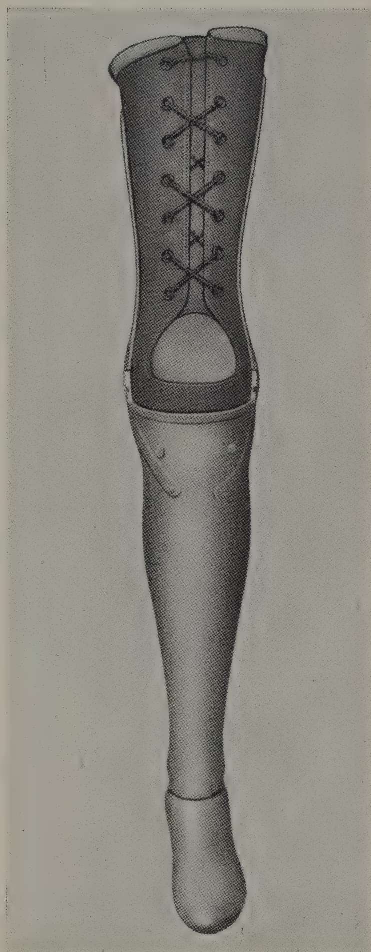

Fig. 13.—Limb for through knee joint amputation.

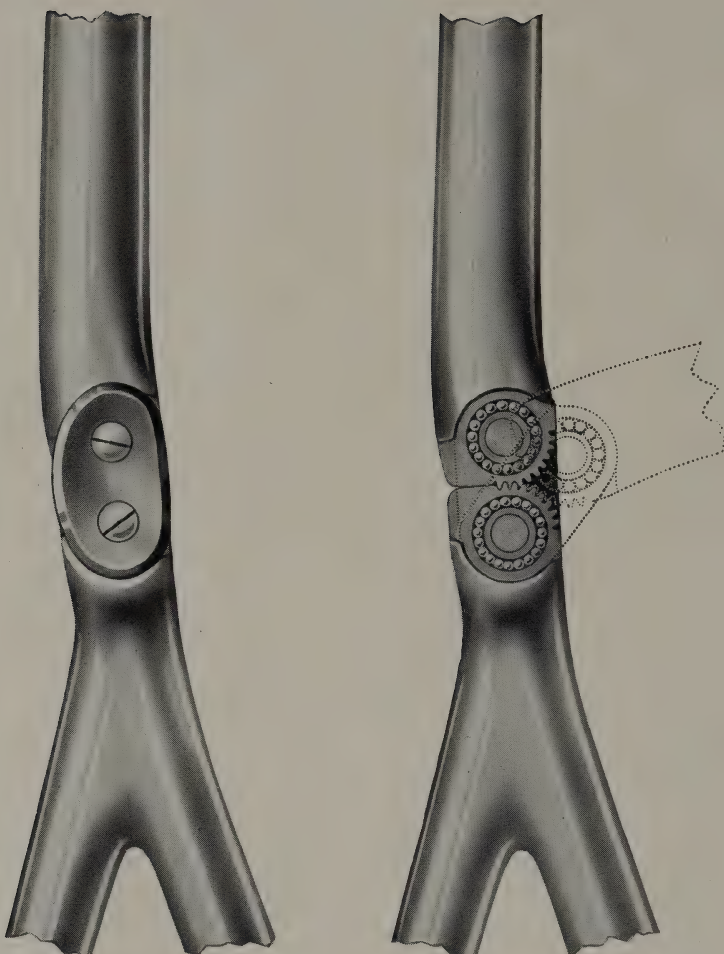

Fig. 14.—The Polycentric Knee Joint.

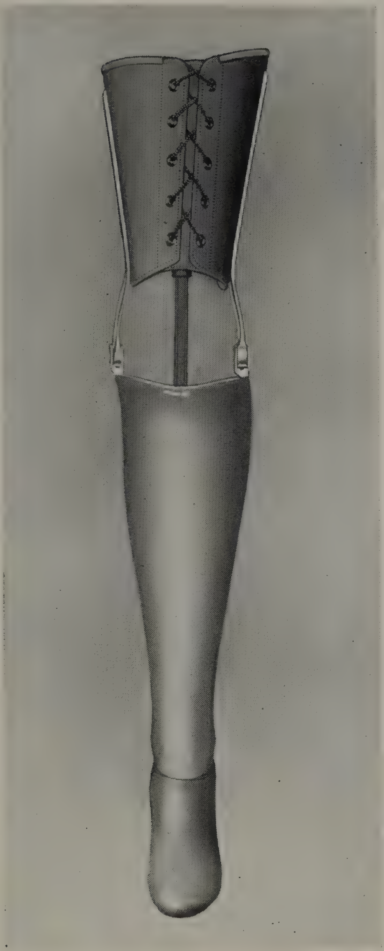

Fig. 15.—The Ministry Standard Limb.

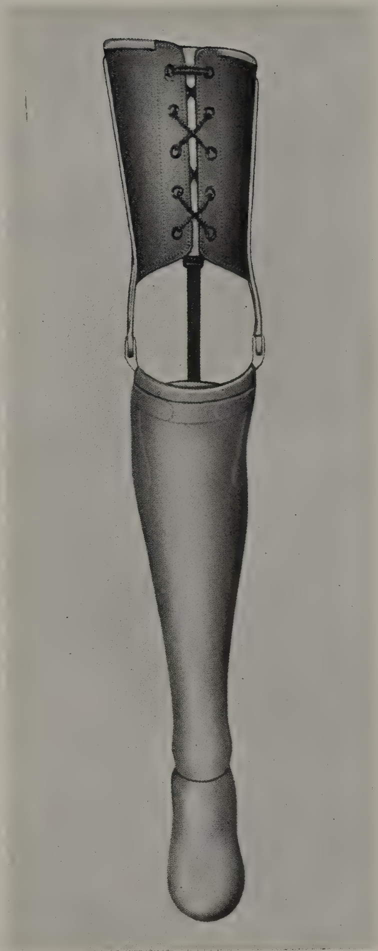

Fig. 16.—Metal Limb for below knee amputation.

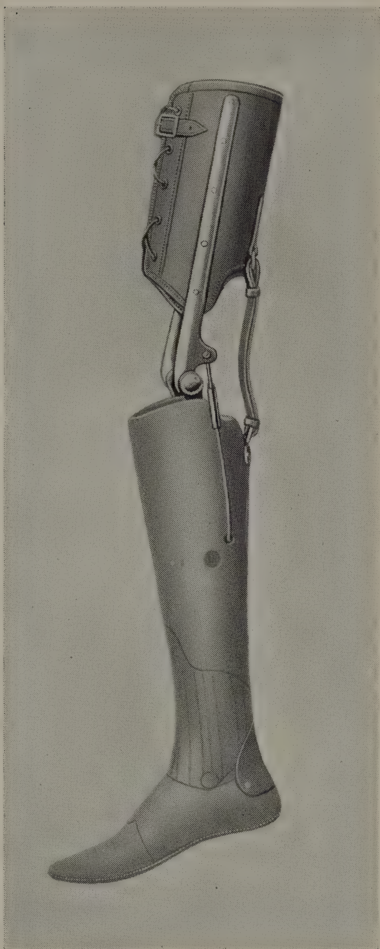

FIG. 17.—Anglesey Limb for below knee amputation.

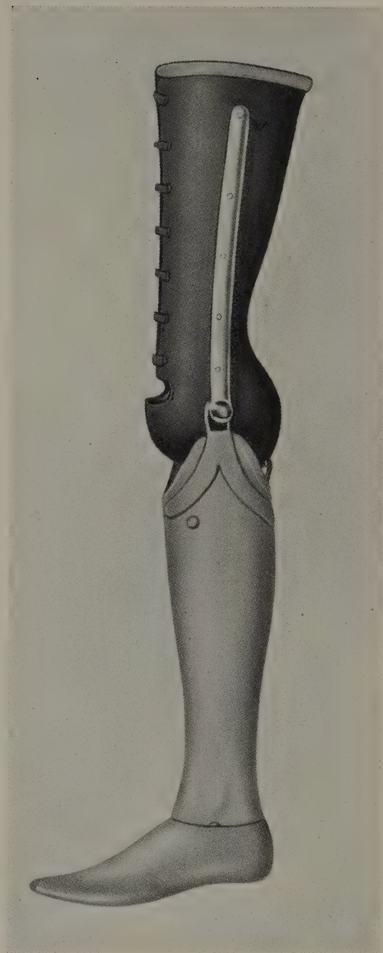

FIG. 18.—Kneeling Leg for short below knee amputation.

interlocking teeth on the opposing faces. Each pair of steels is united by a metal link with two ball races. The illustration (Fig. 14) shows the method of assembly. With this joint, in addition to flexion and extension, a sliding movement is permitted, and its use provides most promising results. Mechanically, the joint appears to be quite as good as the fixed-axis type, and, though the early models were apt to become noisy in action, by redesigning the teeth this defect has now been remedied. The Hanger polycentric can be applied equally well to metal and to wooden limbs and seems to have largely overcome the disadvantages of the fixed-axis joint, for patients say that with it they can walk faster and more easily, that they do not tire so soon, and that walking up and down stairs is less strain. Piston action is distinctly less and flexion beyond a right angle easy to achieve without undue bunching of the tissues behind the knee; this is a great advantage, particularly to those who spend much time sitting. This type of joint, in short, gives greater scope for activity and, for example, enables some who, with the fixed-axis joint, were never able to cycle, to do so in comfort.

The effects of the joint upon the stump are equally noticeable, and some stumps that previously had an abraded and callous surface from long-standing friction are now clearing up in a remarkable manner, whilst bursae are diminishing in size or disappearing entirely. Patients with sensitive stumps, which frequently shewed signs of abrasion, can now use a leg in comfort, and some cases, for whom an ischial-bearing corset would have been considered essential, are able to continue with tibial bearing; doubtless due to the absence of friction. Though it cannot be suggested that the use of this type of joint will in every instance obviate the need for an ischial-bearing corset its use has made such fitting unnecessary in some cases. It may well be that the use of these joints will be to prolong the life of the stump for tibial bearing: a distinct advantage from the patient's point of view.

10. LIMBS FOR THE BELOW-KNEE STUMP—PRESCRIBING AND EXAMINING THE ARTIFICIAL LIMB

Limbs for the below-knee stump may be constructed of either metal or wood.

The metal below-knee limb.—This limb (Fig. 16) has a corset of leather, lacing up anteriorly around the thigh, and to which are riveted laterally the upper steels of the knee joint. At its lower extremity the upper steel articulates with the lower steel by means of a ball-bearing joint, or, in the case of polycentric joints, two ball races go to form the joint on each side. The lower steel is riveted to the upper part of the metal shin, which is shaped to represent the natural calf.

The top of the shin is reinforced for strength by an extra duralumin strip, and a further strip of duralumin, known as a wing plate, covers the lower steel just above its bifurcation, to prevent its being splayed out from the top of the shin by lateral strain when in use. The lower portion of the shin is identical with that already described (p. 24) under the "set-up" of metal legs, carrying a roller-bearing ankle joint and a wooden or a rubber foot.

(1) *The socket.*—Into the top of the shin is fitted the socket, made of stout leather blocked to a cast of the stump. It is constructed as follows :—A plaster cast is taken with the stump in full extension and

carried up just above the articular line of the knee joint. Prior to taking the cast a wet, light, cotton sock is drawn over the stump, and all its bony prominences, and the site of any tender scars, are marked on the sock with indelible pencil, or methylene blue, so that when the cast is removed from the stump these marks appear clearly on its inner surface.

The female cast thus produced is filled with plaster and, when set hard, the outer cast is cut away, leaving the marked sites clearly shewn on the plaster cast. If a socket were moulded to the male cast in its present form it would not fit the stump, because the cast was taken with the stump in relaxation, whilst the socket must fit the shape of the stump when compressed by the weight of the patient. The male cast must therefore be built up to the required shape and this work can only be done by an experienced fitter and cast-maker. The building up is done by driving small pins into the male cast over the marked sites, leaving the head of each pin projecting about $\frac{1}{16}$ to $\frac{1}{8}$ in. above the surface of the cast. Plaster is then added at the appropriate site till it is flush with the pin-head. At other sites the plaster is pared away as required.

When building is completed, stout leather is blocked, when wet, to the cast, and allowed to dry on it; after which it is removed from the cast and stitched up the back, a reinforcing disc of leather being stitched into the bottom of the socket in order to retain the shape. To the outside of the socket, at the top on the front and the back, are stitched blocks of leather, $\frac{1}{2}$ in. wide and $\frac{1}{4}$ in. thick, to prevent the socket, when fitted to the container or shin-top, from sliding down inside it. The whole completed socket is lined with soft leather, which is glued in position.

(2) *The corset.*—There are several types of corsets available for use with the below-knee metal leg.

The soft or short corset is used for tibial-bearing and its function is merely that of retaining the limb in position. The patient should be warned that he is not intended to take any thigh-bearing with this type of corset and, that if he does so, by lacing up the corset too tightly, he may produce stump congestion, and will undoubtedly induce atrophy of the thigh muscles.

The blocked corset (not ischial-bearing) is made of stout blocked leather, and is for use when all the weight cannot be taken on the tibial-bearing surface; with this corset some of the weight is taken on the muscles of the thigh. It does, in time, produce atrophy, but the blocked corset is preferable to the soft corset for thigh-bearing since the softer texture of the latter produces a local constriction. The blocked corset is reserved for those cases that should be fitted with ischial-bearing, but in which for surgical, or perhaps occupational, reasons this fitting is preferred.

The ischial-bearing corset.—This type of corset can be supplied in various forms, according to the severity of the need for ischial bearing, and the simplest type is one that laces anteriorly right up to the top. The patient should be careful to see that the corset is properly laced up when the leg is put on, and not left slack at the top, for otherwise the ischial tuberosity will slip inside the corset. In order to lessen the risk of incorrect lacing a cross strap and buckle are often added to the top of the corset.

The closed-top ischial-bearing corset has the anterior lacing section carried up to within about four inches of the top. At the top the corset

is stitched up; the ischial tuberosity cannot slip into it unless there is some shrinkage of the thigh; and nothing depends upon the patient's lacing it up properly. This corset is therefore used for patients who must not in any circumstances take weight upon the tibial-bearing surfaces.

In the *metal-top ischial-bearing corset*, the top closed portion of the previous type is replaced by duralumin, leaving the leather lacing section below, or dispensing with it entirely. It is prescribed for patients who have bad scars on the middle and lower thigh and who cannot take any pressure on these areas.

(3) *Suspension and other details.*—In the metal below-knee limb hyper-extension at the knee joint is prevented by means of a Keegan back-check strap similar to that used on the through-knee limb.

Suspension of the below-knee limb is by means of a crutch-strap and a back-lift. The former is a forked piece of leather, attached to studs on the front of the shin at the top and to shoulder suspenders. The back-lift is a piece of 2-inch wide elastic with leather ends and is attached to the top of the corset behind and to the suspenders.

A body belt may be used in lieu of suspenders over the shoulders, the fork strap and back lift being attached to it front and back. This means of suspension is useful for those who, for any reason, wish to avoid suspenders over the shoulders, but the weight of the limb tends to drag the belt down on the amputated side, which makes it uncomfortable in some cases.

The wooden below-knee limb.—There are two main types of wooden limbs used by the Ministry of Pensions, viz.:—the Ministry Standard and the Anglesey.

(1) *The Ministry Standard Limb.*—The corset is similar to that described for the metal leg, as are also the knee joints (Fig. 15). The socket and shin are one unit, carved out of willow; there are no jointed sections. The upper part of the shin, now termed the socket, is carved out with pulling tools to measurements and templates of the stump, after which a thin fitting-sock is pulled over the stump, and its bony prominences are marked on the sock with indelible pencil or methylene blue. When the stump is inserted into the socket, abnormal pressure will be indicated by the stain on the willow, and at such points the socket is eased out until the stump is perfectly comfortable.

If there is an abnormal prominence of the anterior tibial tubercle, upon which a painful bursa may form, or if, for any reason, the skin is unusually sensitive at this site, the top of the socket in this area may be cut away and a soft leather section scarf-jointed in its place. Soft sections relieve pressure quite well, but in time tend to lose shape, and when that occurs the socket as a whole ceases to fit, and abrasions appear on the stump because the wooden edges of the scarf-joint become too prominent.

The upper part of the socket may be replaced by an adjustable leather-top section, laced at the back. This type of fitting is of use for the, fortunately, rare "ballooning" stumps, i.e., those that are apt to alter shape frequently. The adjustable leather top to the socket, however, adds to the weight of the limb and becomes hot and uncomfortable.

(2) *The Ministry Standard Limb* (*No. 8A*).—In this the top of the socket is cut away and replaced by certalmid into which is fitted a blocked leather

socket, similar in all respects to that used for metal legs and prepared in the same manner.

The lower end of the shin is fitted with a hardwood ankle-base to which a roller-bearing ankle joint is bolted. The foot is similar to that used for metal legs. Hyperextension at the knee joints is prevented by means of the Keegan back-check, and the limb is suspended in the same way as the metal limb.

Anglesey below-knee legs.—There are two types of Anglesey legs known as the "Modified," and the "Full" Anglesey with outside tendons.

In *The Modified Anglesey* the corset, socket, and knee joints, of fixed-axis type, are as already described for the Ministry Standard limb. The lower end of the shin is, however, different, being constructed so that it forms a tenon-and-mortice joint with the foot. The ankle movement is controlled by a spring in the heel which actuates a catgut tendon. The tendon is nailed to the under side of the heel and passes up through the heel, and through an aperture in the lower end of the shin and ankle base, to pass over two crossed dowel pins fitted in the shin. A free and easy ankle movement is obtained by this mechanism.

The Full Anglesey, with outside tendons (Fig. 17) is similar, except that the tendons passing up into the shin do not pass over dowels in the shin, but are carried up and out of the shin through holes, situated laterally at a level just below the extremity of the stump, to be attached to lugs welded to the upper part of the knee joints. With such an attachment, flexion at the knee causes dorsiflexion of the foot.

The types of corset and methods of suspension used for the Anglesey legs are the same as for any other type of below-knee leg.

Prescribing the type of below-knee limb.—The selection of a below-knee leg lies between the metal leg, the Ministry Standard leg, and the Anglesey types. The Anglesey types are not now prescribed for primary amputations at Roehampton and are given only to those who have used them for years and do not wish to make a change. They require frequent repair to the tenon-and-mortice joints and to the catgut tendons.

The chief differences between the metal and the Ministry Standard limbs are that, for short stumps, the former is lighter and stronger, is better adapted to carry the leather socket, and is also better balanced. If, therefore, the surgical conditions and/or the nature of the stump demand a leather socket, a metal limb is to be recommended. The types of stumps for which a leather socket is preferable are those that are badly scarred, hyperaesthetic, or anaesthetic; those on which bursae are subject to recurrent inflammatory attacks; and those on which the skin appears to be unduly sensitive to pressure and easily abraded, as so often occurs amongst very fair or red-haired people. The leather socket has the disadvantage that it is hotter to wear than the wooden socket and is therefore unsuitable for those who perspire very freely. With a long stump the length of the leather socket increases the weight of the metal leg above that of the wooden leg. When the lightest possible leg is required, the metal leg would be ordered in preference to the wooden, provided the stump is not too long.

Double below-knee amputations should, whenever possible, be supplied with metal legs, on account of the lesser swinging weight.

Metal, in certain conditions, will corrode, and, if a leg is required for patients whose occupations expose them to constant damp or the action of sea-water, the wooden leg may be preferable and may give longer

service. For normal use, however, the metal gives longer service than the willow leg.

The metal limb is rather more expensive, and, when the initial cost is a deciding factor, as it may be in certain cases, the Ministry Standard No. 8A is specially useful.

Examination of the limb.—For testing the fit of the socket the patient should stand erect, taking his weight as equally as possible between the two legs. If he is wearing a short corset, and is therefore taking tibial bearing, the lower border of the patella should be just above the top of the socket. As a rule, it will be found that there is a space of about one quarter of an inch between the top of the socket block and the lower border of the patella. The pressure upon the three bearing surfaces should be evenly distributed, which can be determined only by the fact that the patient does not feel undue pressure on any one spot.

Flexion should be accomplished without undue bunching of the tissues at the back of the knee, but, if the stump is fat and flabby, it is not always possible to avoid this.

The patient will be fitted wearing either one or two socks, according to his preference, but not more than two. Two are more comfortable for tibial bearing, particularly with wooden legs.

The centre of the main screws of the knee joints should be positioned, as already described, at the junction of the anterior threequarters and the posterior quarter of the knee with the centre-line of the patella.

The height of the patient should be taken in the usual way, by placing the thumbs on the anterior superior iliac spines; the one on the amputated side should be slightly lower, especially for those patients who live in hilly country, or have to walk over rough ground. Before taking the height it is desirable to make sure that the heels of the patient's boots or shoes are of the same height, for, occasionally, a patient will add a rubber heel to the shoe on the artificial leg and then complain that the leg seems too long.

The corset, being of the soft short variety, is intended only to retain the limb in position, and should not be tightly laced, but when laced-up should lie comfortably upon the thigh and in an even manner, without gaps between thigh and corset at any point. It should be noted that the side-steels do not press too closely into the thigh. The corset should be laced up by the patient when he is standing up, and not when sitting down. If laced in the sitting position, unless allowance is made, it will be found that the patient on standing has lifted the stump out of the socket and is taking a thigh-bearing on the corset; on this account a number of patients have returned to the fitting centre complaining that the leg is too long and the socket no longer fits.

The patient is asked to walk, and note is taken that the toe does not turn in or out abnormally, and that the knee-joints run true. Failure of the knee joints to run true will be shown by a peculiar twist of the leg as a whole at each step.

When the patient sits erect in a chair the corset should still lie comfortably and evenly upon the thigh, and the side-steels should not be strained, or the stump rise too far out of the socket, if the steels of the knee joints are correctly aligned.

A shrinkage of the stump, common in all primary cases, can be met at first by adding socks and then by lining the socket with felt, until an entirely new socket is needed.

The intention of an ischial-bearing corset is to take weight off the

stump; care should therefore be taken in fitting, to ensure that the corset actually is ischial-bearing, and that the stump is free from pressure in the socket. The patient should also be instructed how to lace up the corset, since failure to adjust it properly will be detrimental to the stump. He should be advised to return to the Fitter immediately he finds the corset no longer fulfilling its proper function. The corset will, in time, stretch at the top and become too supple to carry the weight; this means that a re-fit and re-blocking of the corset are necessary.

11. LIMBS FOR SHORT BELOW-KNEE STUMPS

The configuration of the stump, when short, will affect its ability to make good use of a below-knee limb and, if there is much redundant tissue, this alone may prevent successful fitting, even though the stump may be four inches in length. The shorter the below-knee stump, the greater is the tendency for it to be drawn out of the socket when the knee is flexed. This tendency can be checked by elastics which are stitched to the front of the leather socket block on each side. The upper end of each elastic is fitted with a strap which is attached by means of a buckle to the front of the corset. When elastics of this type are fitted, the socket as a whole is drawn out of the container, and therefore moves up with the stump so that the patient does not lose control of the limb, and friction between the socket and the skin is avoided. The addition of elastics is, therefore, advised for all cases fitted with metal limbs when the stump is four inches or less in length, and also for stumps longer than four inches if they are fat or flabby.

The shortest stump which has been fitted and satisfactorily used with a below-knee leg measured $1\frac{3}{8}$ inches from the inner articular head of the tibia to the end of the bone, but this case was admittedly exceptional, for the stump was thin and poorly covered, and therefore easily retained in the socket, and the patient's mentality and determination were very good. No arbitrary statement can be made that a stump of x inches must be fitted with a kneeling leg, whilst one of y inches could use a below-knee leg. A careful examination of the stump in varying degrees of flexion, of the amount and nature of its redundant tissue,and its toleration of friction and pressure, will indicate the possibilities of success with a below-knee leg.

A rough guide to the behaviour of the stump on flexion can be obtained by placing the palm of the hand behind the extended stump, with the index finger about an inch below the articular line of the knee joint. The patient then slowly flexes the knee-joint and, as he does so, it is to be noted whether, and at what point, the hand becomes pushed off the posterior surface of the stump; the hand, in this instance, representing a socket.

Very short stumps, of the type now under consideration, frequently have adherent scars and there may be hyperaesthesia or anaesthesia following an old sciatic nerve lesion. Some of these cases can be fitted with a below-knee leg, provided ischial bearing is used, but it must be remembered that ischial bearing reduces the functional length of the stump by about an inch. Again, the condition of the stump may be such that no friction of any sort can be tolerated, in which case only a kneeling leg will be suitable.

There are also cases in which there has been some disorganisation of the knee joint with resultant loss of function, and there may be partial or complete ankylosis at the knee. It may then be impossible to fit either

the kneeling leg (Fig. 18) or an ordinary below-knee leg, and a special leg (Figs. 20 and 20A) is required, in which the stump can be accommodated in a socket that is set at the required angle on the container, the latter being cut away to permit the shin and foot to swing on the artificial knee joint in the normal manner. Such a method can, of course, only be used if the stump is not too long, and the degree of flexion not too great. If the degree of flexion is too great to allow of such a fitting, but flexion to 90° is available, a kneeling leg is possible if the stump does not exceed about four inches in length. If it is longer a reamputation to a four-inch stump, or less, may be necessary.

Kneeling leg.—When it has been decided that a kneeling leg should be supplied, a plaster cast is taken with the stump held at a right angle to the thigh. It is carried up to within an inch of perineum, a thin strip of metal having first been laid over the anterior aspect of the thigh and knee. The cast, when set, is removed by cutting down over the metal strip and is then joined once more by plaster bandages. A male cast is then made, and this is compared with a number of metal or wooden master-moulds until the one most nearly resembling it is found. The selected mould is then built up with wood or plaster to the identical shape of the male cast, and a leather socket is blocked to the built-up mould. The leather socket is then cut away just above the knee, and also up the anterior portion, to which a lacing section is fitted which permits of the stump being inserted into the closed, kneeling portion of the socket (Fig. 18).

The socket, thus constructed, is then fitted to the knee-joint steels which, in turn, are attached by rivets to the upper part of the shin. The leg now resembles that used for the through-knee amputation, except that the back of the metal shin must, of necessity, be cut away to a greater degree to allow the stump portion of the socket to pass over it, in flexion of the artificial knee joints.

The leg is hot, heavy and cumbersome to wear and it should be prescribed only when no other type can be made suitable; in this respect, the kneeling leg resembles the tilting-table leg for very short thigh-stumps. On account of extra weight, the wooden shin is not recommended for kneeling legs.

12. THE SYME STUMP AND THE SYME LIMB

Historical and general considerations.—The Syme amputation has probably been the cause of more controversy than any other since the Great War, and its capacity for providing a good stump for modern artificial limbs, and its comparative freedom from trouble, are still matters of discussion.

Professor Syme in his "Principles of Surgery", 4th edition, published in 1856, stated:—"The advantages which I originally anticipated from this operation were—first, the formation of a more useful support for the body than could be obtained from any form of amputation of the leg; and, secondly, the diminution of risk to the patient's life, from the smaller amount of mutilation, the cutting of arterial branches instead of trunks, the leaving entire the medullary hollow and membrane, and the exposure of cancellated bone which is not liable to exfoliate like the dense osseous substance of the shaft." And again—"When recovery is completed, the stump has a bulbous form from the thick cushion of dense textures that cover the heel, and readily admits of being fitted with a boot."

When these quotations are taken together it would appear that Professor Syme considered the provision of a stump that could be fitted with a boot preferable, at that time, to a tibial amputation, for which he suggests no appliance and for which no satisfactory below-knee limb appears to have been designed. This presupposes that the Syme stump could take the weight of the body when fitted with a boot, and we know that at that time little attention was given by the limb makers to prostheses for the lower extremity.

Muirhead Little stated* in 1922—"Syme's amputation, when performed through healthy tissues and followed by aseptic healing, as in the majority of cases in civil life, produces one of the most useful stumps, and one which should be capable of bearing the whole weight of the body on its end without pain. Unfortunately many, if not most, of the examples of this operation among naval and military pensioners, were performed on septic tissues—many of these are not capable of bearing full weight on the ends of their stumps, and in such cases the value of the stump may be considered as inferior to that of an amputation at or near the middle of the leg, and many patients who have had reamputation performed after wearing prostheses on imperfect Syme stumps have much preferred their latter condition." "The æsthetic objections to Syme's amputation remain, however. It necessitates a prosthesis which is comparatively heavy, weighing from three to four pounds, and the ankle is necessarily clumsy, so that an ordinary boot cannot be worn; and although an ordinary Oxford shoe is applicable, the artificial ankle bulges in an unsightly manner above it. For working purposes, when appearances are not to be considered, a Syme stump may be fitted with a simple stump boot or elephant foot, for which it is well suited."

Muirhead Little, therefore, viewed the Syme amputation with some reserve, and did not regard it as an unqualified success, though his experience agreed with that of Professor Syme that the stump was well suited to a simple stump boot, and this opinion was widely held for some years after the Great War. So long as the Syme stump was capable of taking all the body-weight upon the stump-end, it proved very valuable, as it enabled the patient to move about his home without having to wear an appliance that was somewhat unsightly. The great majority of Syme stumps were fitted, in those days, with full end-bearing, but when this was not possible ischial-bearing was the alternative adopted; the Syme limb having added to it knee joints, side steels, and full ischial bearing corset, making it a heavy and cumbersome appliance. When reamputation had to be performed on these cases, and a below-knee limb was supplied, the patients soon appreciated the neat appearance, comfort, and comparative lightness of the new appliance and expressed no regrets for the loss of the Syme stump.

It has been suggested that opinions based upon experience of War cases should not condemn the Syme, as a stump, since sepsis was prevalent amongst War cases and predisposed to failure; but sepsis was actually not so common as might be supposed. Experience at Roehampton supports the view that, when there is pre-existing sepsis, the Syme stump will not tolerate end-bearing for long, if at all. Unanimity, however, seems lacking on this point; Syme amputations are still occasionally done when a septic history is known, and many of these cannot be fitted with a limb until reamputation has been performed.

In the year 1924 the amputation cases dealt with by the Roehampton

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* Op. cit. (p. 15)

Centre were reviewed and the amputations were classified according to site. At that time there were 54 Syme amputations on the books of the Centre. Of these, three were reamputated between 1920 and 1924, and 35 between 1925 and 1933. In only 10 of these 38 cases was there definite evidence of sepsis prior to amputation. Sepsis is not, therefore, the only cause of failure of the Syme stump, but, when present, merely contributes towards its failure—which is due to a combination of factors.

While it is agreed that the Syme stump gives good service so long as end-bearing can be tolerated, the following figures are of interest. 22 Syme stump cases were taken at random and investigated on their ability to take end-bearing. The results were :—

1	case	took	end-bearing	for	16	years.
1	,,	,,	,,	,,	14	,,
1	,,	,,	,,	,,	13	,,
1	,,	,,	,,	,,	12	,,
1	,,	,,	,,	,,	11	,,
1	,,	,,	,,	,,	10	,,
4	,,	,,	,,	,,	9	,,
1	,,	,,	,,	,,	7	,,
4	,,	,,	,,	,,	6	,,
2	,,	,,	,,	,,	5	,,
1	,,	,,	,,	,,	4	,,
2	,,	,,	,,	,,	3	,,
1	,,	,,	,,	,,	2	,,
1	,,	,,	,,	,,	less than 1 year.	

The average length of time these cases were able to take full end-bearing was, therefore, $7\frac{1}{2}$ years. The 38 reamputated cases referred to above had, on the average, retained their Syme stumps for 8–9 years.

Owing to the trouble experienced with Syme stumps, and the fact that some patients were unwilling to run the risk of reamputation, and preferred to retain a painful stump, a different method of fitting was adopted, the weight being taken, either entirely or in part, in the same manner as in an ordinary below-knee amputation. Partial end-bearing could then be allowed for. Strictly speaking, therefore, Syme stumps are now fitted as if they were long below-knee stumps and their liability to break down is proportionately lessened; but a Syme amputation now merely provides a long below-knee stump that has all the circulatory and other disadvantages of any long stump, and is not to be compared with the ideal below-knee stump in usefulness or longevity.

Defects contributing to ultimate breakdown of the Syme stump.—The factors or defects which contribute to the ultimate breakdown of the Syme stump and render reamputation necessary are, briefly, as follows :—

(1) *The end-bearing pad* is dense in structure, poorly nourished with blood, and attached to the stump anteriorly by the strength of scar tissue. Weight bearing upon this pad often results in displacement, which in some cases has been so great that the extremities of the tibia and fibula have been exposed to direct end-bearing pressure. This displacement is quite incurable, and though the limb may retain the pad in position whilst the limb is actually worn, the patient appears to be taking his weight upon a movable ball of rubber.

(2) *The anterior scar* suffers considerable traction, particularly when the end-bearing pad is slightly displaced. Every step the patient takes

causes the tissues to drag the scar and callosity appears just beneath the anterior transverse scar in its whole extent. This may in time involve the scar itself and become very troublesome. It is not uncommon for the scar to split and ulcerate as a result of traction, and, if it does so, healing is a long process.

(3) *Callosities* are commonly found upon the under surface of the end-bearing pad. These may be very tender, and end-bearing becomes impossible. Ulceration, moreover, is quite common and frequently cannot be healed.

(4) *Nerve bulbs* are as common as in any other stump but, owing to the dense tissues in which they grow, they are probably more troublesome, and give more pain. Many reamputations have been found necessary for this cause alone.

(5) *Poor circulation* is to be found, as in any long stump, but is perhaps more pronounced at an earlier stage. The stump end becomes cold and red and later turns a purple colour, extending some way up the stump, which, by this time, is very painful. This is the cause of most of the reamputations of Syme stumps.

(6) *The bone condition* usually shews an abnormal degree of rarefaction. This has been the only condition found in some painful stumps, but reamputation has proved the only effective cure. Painful periostitis of the anterior border of the tibia is very common. The cause is friction between the bone, which is poorly covered at this site, and the socket. The insertion of two strips of $\frac{1}{4}$ in. sheet sponge rubber beneath the lining of the socket on either side of the tibial border is the only means of avoiding the friction. Many limb-makers, however, appear to dislike this method of coping with the trouble and seem to think, quite erroneously, that the use of any form of padding in a socket is a confession of inability to provide a good fit.

The Syme limb.—There were formerly many types of Syme appliances but two only are now used at Roehampton: one, the open ended socket with two lateral steels, anterior bifurcating steel, and roller-bearing ankle joint (Fig. 19); the other with a closed end, two lateral steels and tongue, and bolt-type ankle joint. The former is the more satisfactory, as the stump is better ventilated, being unenclosed at the end, and the top of the socket is made to take a true tibial bearing so that, when required, no weight at all need be taken upon the end-pad of the stump. The open end makes it possible to ascertain exactly how much weight is being taken upon the end of the stump.

If the stump condition deteriorates to the extent that no weight can be taken at the end, and tibial bearing alone is insufficient to free the end and lower part of the stump from pressure, side steels with knee joints and leather thigh-corset can be added. The added weight of the limb is excessive, however, when it is realised how small an amount of natural limb the artificial appliance is replacing.

13. PERMANENT PEG LEGS.

Permanent peg legs can be supplied in metal (Fig. 21) or wood (Fig. 22) for most amputations of the lower extremity, and, unlike the plaster and fibre pylons that are used as temporary prostheses, they are intended to last indefinitely. There are various reasons for supplying a peg leg

in preference to a leg with a foot, but it is clear that with a peg leg the gait can never be good, whether the amputation is above or below the knee. The above-knee peg is used with the knee locked in the position of full extension when walking, and the wearer walks with an abducted gait, swinging the peg with a circular motion. The wearer of the below-knee peg, though he may have the normal use of his natural knee joint, rarely makes use of it, but keeps the joint slightly flexed most of the time when walking.

Reasons for their supply.—The indications for the supply of a peg leg in preference to a fully articulated leg with a foot, may be classed as medical, occupational, and financial.

(1) *Surgical and Medical.*—(*a*) *Above-knee amputations.*—Patients with high thigh-amputation are often in a very weak and debilitated condition as the result of the shock of the operation and, possibly, a preceding exhausting illness. This condition is specially common in those with disarticulation at the hip-joint, for whom a tilting-table limb will eventually be prescribed. By the time the stump is ready for an artificial limb, these patients should, as far as possible, be able to get out in the open air, and to take a little exercise to tone up the muscles and generally improve the health, but, in this type of case, it is frequently impossible to supply a fully articulated limb of the tilting-table variety, on account of its weight, which may be too great for the patient's debilitated state and cause him to become dispirited at the irksome task of using it. Some have become permanent invalids, confined to the use of crutches or a wheel chair, through being supplied in the first instance with a limb that tired them too much. For such the metal tilting-table above-knee peg leg is of the greatest advantage The saving in weight by the use of a metal peg-leg may amount, in a high amputation, to about $1\frac{1}{2}$ to 2 lbs.; but it is not only the saving in gross weight of the limb that is of value, but also the saving of swinging weight below the knee, and the fact that a boot, which may weigh a pound or more, is unnecessary. It is, however, difficult to persuade some patients to accept a prosthesis against which there appears to be much prejudice. The average amputee is usually most insistent that when a limb is fitted he shall appear normal, though he apparently has no objection to using crutches without a limb. It is necessary, therefore, to put the facts of the case very clearly to the patient, telling him that, if he insists on commencing with a fully articulated leg, he may ruin his chances of using a limb successfully in the future; but, if he will consent to use a peg-leg (usually for six months to a year) until his general health has improved and his strength returned, he will have greater confidence and success with a limb.

In construction, the peg-leg is identical with that of the articulated leg in so far as the socket and thigh piece of the tilting table or above-knee leg is concerned. The knee-piece differs, having no mechanism other than the knee-lock, which is automatic in action; i.e., the patient presses down a button on the front of the knee when he wishes to sit down, but when standing up the knee automatically locks in extension. Into the under surface of the knee-cup is fitted a tubular metal peg and to its extremity is fitted a rubber peg-end.

(*b*) *Below-knee amputations.*—No medical reasons can be advanced for the supply of the ordinary peg leg for these cases. The type of case, now fortunately rare, where the stump is so long that there is insufficient clearance between the stump end and the ground for the fitting of a

mechanical ankle joint and foot, such as abnormal Syme stumps and Pirogoff's amputations, may be fitted with a stump boot.

(2) *Occupational.*—Theoretically, the demand for peg legs on occupational grounds should be much greater than it actually is, for there are many occupations in which the presence of an artificial foot would seem to be nothing but a nuisance to the patient, and for fishermen, longshoremen, workers in claypits, watchmen and miners a peg leg might reasonably be considered the most suitable type of artificial limb.

It is, however, difficult to persuade patients to accept peg legs, even though many admit they would be more useful for work. The amputee usually objects so much to a display of his disablement that he would rather wear a heavier and more cumbersome appliance, which looks normal, than a light peg leg; except, of course, those who elect to capitalise their disablement by begging, of whom many are known to wear a fully articulated leg when not exercising their profession. Any occupation that entails walking in damp places may result in considerable damage to the ankle-joint mechanism and foot, and one would not expect a farmer, who has to walk much over wet ploughed fields, to prefer to do so with an artificial foot and boot, the latter carrying a pound or more of heavy soil on it, rather than to use a broad-ended peg leg; yet many of them do so.

For those patients who are in possession of two articulated limbs, and who decide that a peg is more suitable for their work, the ankle-base and foot can be removed from the leg and a peg-end substituted, whether the leg be made of metal or willow.

(3) *Financial.*—The peg leg is cheaper to produce than a fully articulated leg, particularly a metal one, and, as there is no mechanism of the knee or ankle to keep in order, the repairs needed are little beyond renewal of the rubber of the peg-end, and occasional renewal of sockets, necessitated by changes in the stump. The peg leg of metal or of willow is useful, therefore, for those who have to purchase their own limbs and cannot afford the more expensive article.

Chelsea Peg-Legs.—The Chelsea (Fig. 23) is used for patients with short below-knee amputations who, for various reasons, are unable to make use of an ordinary below-knee limb. This type of peg has been in use for a great number of years and its design may have had a share in the selection of the old site of section, i.e., four inches, or a hand-breadth, below the knee. The peg is fitted with a wide knee-cup or support, suitably padded, in which the flexed knee rests. A wooden upright extends from the outer side of the cup to the level of the waist, to which it is attached by means of a strap. A wooden peg-stick is fitted to the under side of the knee-cup. There are several conditions found in below-knee stumps which make such a limb desirable, as, for example, stumps subject to dermatitis which will not tolerate the socket of a below-knee limb on account of the aggravating effect of its heat. They can, however, be fitted with a Chelsea peg, since there is good ventilation and no general friction. Also, in cases of thrombo-angiitis obliterans which have been amputated below the knee and are unable to use an ordinary below-knee limb owing to the risk of abrasions, the Chelsea peg enables the patient to get about without much risk to the stump, when reamputation to above the knee is not advised.

Short pegs for double amputations above the knee.—The first pair of limbs supplied after the amputation should be several inches shorter

than the original height of the patient in order that he may first learn to balance himself on them. Later it may be possible gradually to increase the height.

With the double above-knee amputation it is often found unsuitable to start with articulated legs, especially when the patient is heavily built and one or both the stumps are short. For this type of case, two thigh sockets are made of metal or wood and a peg-end of from four to five inches in diameter is fitted directly beneath the socket. With these short pegs the patient can get about well, and learn to balance very easily. Some cases never progress further than this stage, whilst others, at a later date, have articulated legs made with which they walk well, but retain the short pegs for work in the garden, etc. Apart from teaching a patient to balance himself, the short pegs develop the power of the stumps, which is important if fully articulated legs are to be used later.

14. SOME COMMON CONDITIONS AFFECTING AMPUTATION STUMPS OF THE LOWER EXTREMITIES.

The term " ideal " has hitherto been applied to one above- and one below-knee stump, and it has been said that such stumps give little trouble compared with those amputated at any other level. Though ideal stumps will rarely give any trouble for many years, yet conditions do arise occasionally in them (but less frequently than in other stumps), which require attention, and, as time goes on, the breakdown of stumps becomes more noticeable. This deterioration may be due to a diminution of stump tolerance to the artificial limb, through lessening of tissue resistance. It cannot be considered due to bad limb fitting, since the standard of fitting is now higher than it has ever been, and the principles involved are more clearly defined and understood. Some of the commoner conditions are as follows :—

"Roll of flesh".—As the pensioners get older they seem to become more difficult to fit and, in many, stumps change more frequently as with increasing age they tend to put on weight, and what is termed the " Roll of Flesh " is produced.

When a limb is fitted to a fat and flabby stump there is always a tendency for a roll of flesh to appear over the top of the rim of the socket in the adductor region, and when this occurs careful fitting is necessary. At one time a method of fitting known as the " Plug-fit " was adopted, which meant that the patient was taking a muscle-bearing by forcing his stump into a socket which would now be considered much too small for it, and no weight was borne upon the ischial tuberosity. The roll of flesh was present to some degree in all such cases, and in course of time developed adhesions. If the adhesions had not long been present it was possible to reduce the roll in stages, by including a little more flesh within the socket each time a new socket was required. The nature and size of the roll may, however, prevent any portion of it being contained in the socket and there is then no alternative but to continue the " plug-fit", or remove the redundant tissue by operation.

Sometimes the first fitting was correct, with a true ischial bearing, but the stump may have increased in size and the patient, instead of returning to his fitter for adjustment, continues to wear the limb so that the roll pushes the socket off the stump and the ischial bearing is lost.

Sebaceous adenomata and furunculosis.—Although occasionally observed on below-knee stumps, this condition is almost always confined to above-knee stumps. When the cysts become infected with staphylococci a crop of very painful boils may appear along a line corresponding with the top inner edge of the socket in the adductor region, extending eventually downwards within the socket. They may also coalesce to form a solid mass, similar to a carbuncle, with several points on the surface discharging pus. The cause may be bad fitting, but is generally due to a combination of bad fitting and uncleanliness on the patient's part.

The treatment is complete abstention from limb wearing until the condition has entirely cleared up and the socket is refitted; the daily application of Ung. Hydrarg. Ammon. Dil. is of value, together with frequent warm bathing of the part. Treatment may be required for a month or more. Vaccines and collosal manganese, etc., have all been tried without much success. Some advanced cases will not respond to treatment and the skin remains purple, œdematous and septic. In such cases, after cleaning up as much as possible with fomentations, the whole area must be excised. This has been done many times, with success, by Jenner Verrall, who has devised a method which places the resultant scar as low as possible and where it is not so likely to be affected by the limb.

This condition was at one time very prevalent and many patients were from time to time incapacitated by it. Nowadays, however, all sockets are shaped to give ample room in the adductor region, so that furunculosis due to bad fitting is almost abolished, the number of cases requiring attention, compared with past years, being very small indeed.

Osteophytes or spurs.—Osteophytes or spurs grow from the cut ends of bones in amputation stumps (Fig. 24). They are very common in thigh amputations and may be observed six months after the operation. They grow upwards in a postero-internal direction and, even though they may reach the length of 2 ins. or more and have a sharp pointed extremity, they rarely cause any trouble. The direction of growth is probably due to the action of the adductor muscles pulling on the periostium. This type of spur can cause trouble if it grows into scar tissue, or presses on a nerve-bulb. Pain in the stump is, however, often attributed to a spur when it is due to some other cause. Removal of the spur is of no benefit and it will probably be replaced by another outgrowth in a few months.

The osteophyte may grow from the whole circumference of the cut edge of the femur in a cauliflower shape, forming a rugged bony mass at the stump end. The mushroom-shaped osteophyte is one which grows from the whole or part of the cut edge of the femur; the direction of the growth is slightly outwards and downwards. The outgrowths do not appear to cause any troublesome symptoms. Both types are so rare that less than a dozen cases have been seen in the past fifteen or more years.

It appears to make no difference what method is adopted when operating; the spur cannot be prevented from growing, though in many cases the growth is very small.

Nerve bulbs.—These are present in all stumps and can be palpated in most above-knee stumps. Under favourable conditions they should not cause any symptoms, but if they do cause trouble there is usually a definite and discernible reason. Certain obvious causes for a nerve bulb becoming painful may be classified as follows.

(1) *Trauma.*—(*a*) *Direct:* If traction is made upon the nerve prior to

section, a painful nerve may be expected. Apart from this, however, section alone is sufficient to leave a nerve-ending which is painful for some time. It is sometimes suggested that injection of the nerve trunk with alcohol will obviate the after effects of section, but experience of this procedure has shewn that cases are more often worse than better after the injection, and it is not recommended. Any trauma, such as massage, applied to the nerve-ending after amputation is likely to produce a painful bulb, and should therefore be avoided. Incorrect limb fitting can also be responsible for painful nerve bulbs.

(*b*) *Indirect trauma* results from the piston action of the stump within the socket when the tissues surrounding the nerve bulb are adherent to overlying scars.

(2) *Sepsis.*—This is the commonest cause of a painful nerve. In long standing sepsis prior to amputation, there is probably a neuritis of the nerve trunk which may have extended well above the site of the ultimate amputation. Sepsis supervening after amputation will cause the same condition in some cases. It is usually found that the length of time the sepsis has persisted prior to amputation has a direct bearing upon the severity of pain in the subsequent nerve bulb. In these cases it is better to delay limb-fitting for some time.

(3) *Alcohol.*—The effects of alcohol taken internally vary very much in different cases, but there is ample evidence to show that pain in nerve bulbs is aggravated by malt liquors rather than by spirits. Some patients find that one pint of beer is sufficient to cause a bulb to become painful.

The treatment of painful bulbs has changed during the past few years. It was customary at one time to remove all painful bulbs, with good results in some cases, but in others, the operation was a complete failure; a new, and often still more painful, bulb forming within a short time. Now, treatment is related to cause and if that is an ill-fitting limb, the remedy is easy; similarly, the effects of trauma are known and can be avoided; whilst alcohol, as a possible cause, can be dealt with in most cases.

The effects of sepsis are more difficult to deal with and the removal of a bulb from a neuritic trunk will give but temporary relief, as will the subsequent removal of newly-formed bulbs. The likelihood of the production of a painful bulb in septic cases can be lessened considerably if more time is allowed to elapse between the amputation and the fitting of the limb; in some cases a lapse of six months to a year has been beneficial and allowed the stump to become painfree.

The most satisfactory treatment appears to be the use of anodic galvanism and a bromide mixture, and while such treatment is being given the patient should not use his limb.

In some cases the pain experienced in the nerve trunks is less severe and comes on as attacks which last a few days and cause trouble mainly at night when the limb is not in use. The application of Ung. Methyl. Salicyl. Co. to the affected area on the stump, afterwards covering the part by a hot flannel, or covered rubber hot water-bottle, may give relief. The injection of alcohol into the trunk appears to aggravate the pain after a day or so. The use of hypnotics is not recommended, except for the most severe cases and then only under strict supervision.

Circulatory defects.—Defective circulation in stumps is confined almost entirely to above-knee stumps which are longer than twelve inches, and below-knee stumps over seven inches in length. The early symptoms are

those of pain and reddening of the integuments at the stump extremity. Later, the stump becomes cold to the touch and the colour varies from deep red to a dark plum; the stump is then particularly susceptible to abrasions which invariably ulcerate.

When this condition is first noticed in an above-knee stump the only action, from a limb-fitting point of view, is to ensure that an accurate ischial bearing is being taken, and that there is no abnormal constriction in the adductor region. As a general rule, however, the condition is not caused by faulty limb fitting, but by the length and nature of the stump. When the condition becomes intolerable a reamputation is necessary, and the bone section must be made at a high level, in order to secure healthy skin for the flaps and to ensure that the section is made through healthy bone. When the condition arises in a below-knee stump the patient should be fitted to take weight on the ischial tuberosity, and this may postpone for a time the inevitable reamputation.

Bursae.—Below-knee amputations fitted with tibial bearing usually develop three bursæ:—located over the anterior tubercle of the tibia, the head of the fibula and the inner tuberosity of the tibia. They are a natural protection to the part and, provided they do not become unduly large or subject to recurrent attacks of inflammation, they should not be removed. They are due to pressure and to friction induced by piston action of the stump in the socket. Should the bursæ give trouble the best treatment is the supply of an ischial-bearing corset. If merely tapped, they recur, whilst if excised an ischial-bearing corset will still be required on account of the scar over the tibial-bearing surface.

Bursæ are now becoming less common, owing to the increasing use of ischial-bearing corsets. Though all above-knee stumps are fitted to take weight upon the ischial tuberosity and friction at this site is unavoidable, only once during the past seventeen years has a bursa been seen at this site.

15. THROMBO-ANGIITIS OBLITERANS. THE PHANTOM LIMB. SPECIAL PROSTHESES FOR CONGENITAL DEFORMITIES.

Thrombo-angiitis obliterans.—The recognition of this condition some years ago, and the amputations which in so many cases resulted from it, caused much uncertainty in the minds of those concerned with the supply and fitting of artificial legs and arms. Since some apparently normal stumps, especially long ones, suffer from defective circulation it seemed that, theoretically at least, stumps resulting from thrombo-angiitis might not be suitable for an artificial limb. During the past few years some sixty amputations on account of thrombo-angiitis obliterans have been dealt with from the limb-fitting aspect and from this experience the following facts emerge.

A primary above-knee amputation provides a stump which, when fitted with a suitable limb, gives satisfactory service. Some patients, observed over a period of four years, have used their limbs continuously, and played golf regularly, with no harmful effect to the stump.

Amputations performed below the knee do not show so satisfactory a result; in fact, so unsatisfactory have many of them been that it is impossible to predict that the stump will permit the use of a limb. Some have done so for a time but later on an abrasion has appeared: they may heal after prolonged treatment but will break down again when a limb

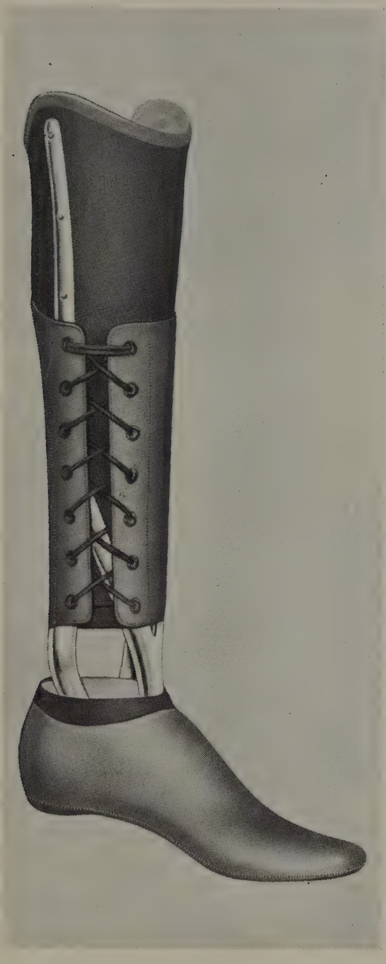

Fig. 19.—Limb with open end for the Syme amputation.

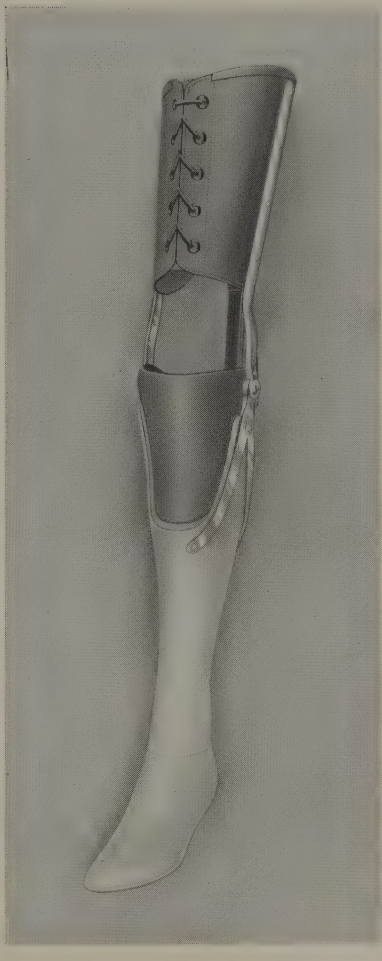

Fig. 20.—Limb for below knee amputation with ankylosed knee, standing position. For sitting position see Fig. 20A.

FIG. 20A.—Limb for below knee amputation with ankylosed knee, sitting position.

FIG. 21.—Metal Peg Leg for above knee amputation.

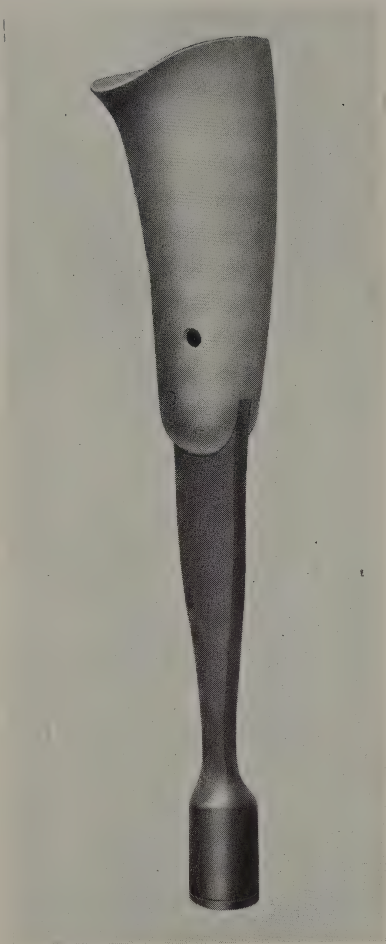

FIG. 22.—Wood Peg Leg for above knee amputation.

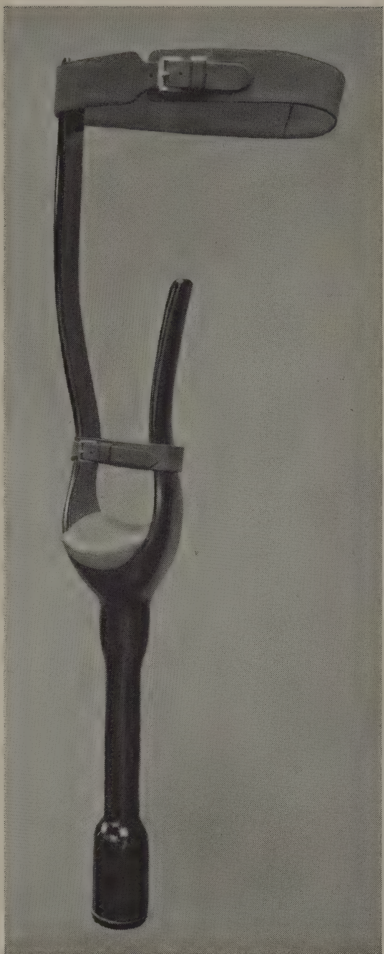

Fig. 23.—The Chelsea Peg Leg.

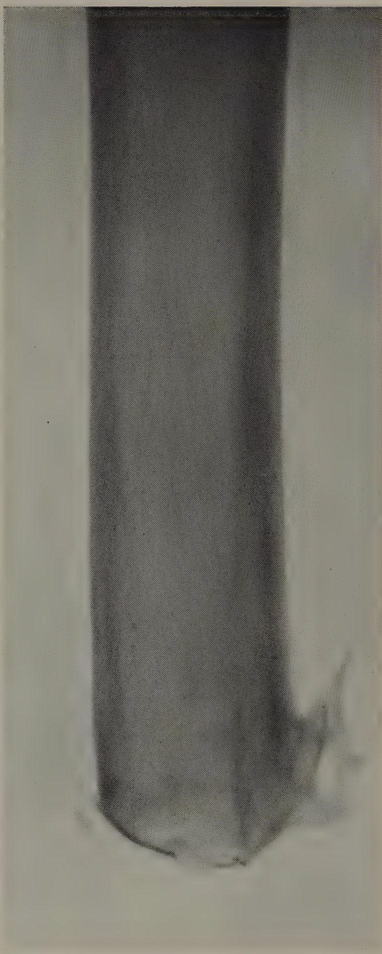

Fig. 24.—Common form of osteophyte on the femur.

is used. Ischial-bearing is essential in these cases, but even this method of fitting does not eliminate the risk of abrasion. The shorter the stump is below the knee the better the circulation; but even so, a short stump will not remain in good condition indefinitely after the amputation if an ordinary below-knee limb is worn. Provided the below-knee stump does not exceed four inches, a kneeling limb can be provided and gives the best hope of success since, with this type of fitting, there is less friction on the stump.

Many patients have eventually a double amputation, and, when this happens, there is much to be said in favour of retaining one knee joint, even if it be immobilised within a kneeling socket, which may be used in conjunction with an above-knee leg on the other side. It would seem, therefore, that a double amputation being a possibility in all cases, one above-knee stump can be counted upon to remain satisfactory, as can also a very short below-knee if fitted with a kneeling leg, though for it the prognosis is not so good. The ideal length of below-knee stump when thrombo angiitis is present appears to be not greater than 4 inches.

It might appear that a patient having suffered above-knee amputation on one side should be amputated on the other, immediately suspicion is aroused that the condition is present in the other foot. A number of such cases have, however, cleared up, despite the fact that physical signs of the presence of the condition were apparent. One patient had to undergo above-knee amputation of the right thigh whilst the condition was beginning to manifest itself in the left great toe, for which it was decided to amputate four inches below the knee if necessary but, in the meantime, the case was watched closely and courses of carnacton were given. The great toe cleared up but suspicious patches of discoloration appeared on the dorsum of the left foot. Meanwhile an above-knee leg was supplied with which the patient walked well. After crutches had been discarded and the strain thus relieved, the left foot cleared up entirely and the patient now plays golf and other games, and four years after the original amputation requires no treatment.

Amputations of the upper extremity appear to give little trouble, probably because artificial arms are not weight-bearing limbs.

The Phantom Limb.—All amputees, whether the amputation is of the upper or the lower extremity, experience at some time or another what is termed a " Phantom Limb; " that is, they are conscious of feeling the lost member and can describe various movements in it. This sensation is not, however, always accompanied by pain, and it is possible to discriminate between the painful and the non-painful phantom, both in cause and treatment. Whether a feeling of discomfort will be described as one of pain will depend upon the individual patient.

The sensation of the presence of the missing foot or hand may change to one of discomfort, with perhaps some pain, in certain conditions, such as changes in the weather, or in the circulation of the stump. Patients resident in tropical countries say they have a discomfort in the missing foot at the commencement of the wet season which is relieved by going to a hill station. This sensation may be, and often is, aggravated by the presence of adherent scars dragging upon a nerve ending, and by other local conditions. Surgical interference will probably eliminate the cause for aggravation but will not cure the discomfort. The feeling of the presence of the missing foot soon ceases to trouble the patient; sometimes it disappears when a limb is worn, but in others it persists, whether the limb is worn or not, but requires no treatment.

In the painful type of phantom limb there is definite pain, in greater or lesser degree, which does not seem to be a development from a painless condition, but is painful from the outset. In the majority of cases the pain appears very soon after the amputation and before any attempt at limb-fitting. It is, therefore, not induced by a painful bulb, and nerve bulbs appear to have no relation to the condition, though they may aggravate it in both the painful and non-painful variety. The pain of this phantom is continuous but varies in intensity from time to time, being worse during climatic changes and particularly when the patient's general health is poor, which is often the result of the pain and resultant loss of sleep, so that a vicious circle is set up.

The character of the pain varies considerably. It may be a dull ache, or a throbbing of the whole of the missing hand or foot which may feel generally swollen and about to burst. Sometimes patients complain that the fingers are being forcibly flexed into the palm of the hand, or the toes are being contracted. Shooting or stabbing pains are sometimes described. In such a case it is usual to find what might be described as a perfect stump, with no objective signs. Very rarely can a painful bulb be palpated, and if one is present pressure upon it does not aggravate the symptoms. The pain then appears to be of central origin.

The wearing of an artificial limb in itself neither improves nor worsens the condition, but in many cases when a limb is worn continuously upon a lower extremity stump the symptoms become less severe. In extreme cases the stump is generally hypersensitive and the patient will not attempt to put a limb on.

When once a genuine painful phantom is diagnosed there is very little active treatment which is of any value, surgical treatment being quite useless. The condition must, however, be carefully differentiated from the neuritis of long-standing sepsis, painful nerve bulbs associated with adherent scars, etc., most of which respond to surgical treatment. Moreover, the surgical measures which, in some cases, improve the pain caused by septic neuritis, if applied to a painful phantom limb will, as a rule, only aggravate the condition. Difficulties also arise because of other conditions which might aggravate the pain, but experience shows that, whilst symptoms caused by these conditions are relieved by operation, those of the phantom nature are not. Several cases of this type have been seen amongst amputations of the upper extremity where the patient commenced with a through-wrist amputation with phantom hand and ended with a disarticulation at the shoulder without any relief from the pain. Posterior root section has been tried without success and cordotomy is equally a failure. On the assumption that the pain might be due to vaso-motor disturbances, the Leriche operation has been tried, again without success. On the assumption, for which there is much support, that the condition is central in origin, treatment by suggestion has given satisfactory results in some cases; others have been equally well dealt with by providing a good limb and persuading the patient to wear it, often a difficult task. The provision of a limb, and the willingness of the patient to persevere with it despite pain, coupled with congenial employment, preferably of a mental nature, will so take the patient's mind off his stump condition that it may in time cease to trouble him.

Special limbs for congenital malformations and deformities.—The use of specially constructed artificial limbs for these conditions has been of the greatest value in enabling deformed children to walk, and, if the patient is a girl, the deformity can be well concealed. The cost of these

special appliances is of necessity greater than that of an ordinary artificial limb, since each has to be designed and constructed to meet the special requirements of the case and few standardized mechanical parts can be used. The fitting usually presents considerable difficulty, requiring much experimental work, some of which is of no avail, but nevertheless adds to the cost of the finished article. The types of the deformities which have to be dealt with vary so greatly that it is impossible to classify them in any useful manner. The following brief descriptions of cases actually fitted with limbs will, however, indicate something of what can be done in the way of attempting to restore the cripple to some form of normality by artificial means, and the value of such attempts in improving the young patient's outlook on life.

(1) *A girl* 8 *years of age.*—This child had never walked, but could only slide about the floor, indoors, on her buttocks. She had a double congenital dislocation of the hip joints, the length of each femur being but 6½ inches. There was no tibia or fibula. Both feet were inverted and internally rotated with the soles uppermost, and were attached to the end of the femurs by fibrous union. No amputation was necessary before the fitting of the limbs. Limbs were fitted with which she can walk without sticks when indoors, but with which she uses sticks when walking out of doors.

She is now 16 years of age, five feet tall, happy, and cheerful, earning her living as a Typist.

(2) *A girl* 18 *years of age* with double malformation of the femurs, which were ankylosed at the hip joints, marked genu valgum, and feet of abnormally large dimensions. The distance from the perineum to the end of the toes was sixteen inches. She could only waddle or shuffle along with the aid of two sticks, having but very little movement at the hip joints.

The supply of artificial legs of correct length increased the amount of movement and she could obtain a reasonably long stride. No amputation was necessary and, though previously she had never walked out of doors, she is now very active.

Her original height when standing was 3 ft. 4 inches; her present height is 5 ft. She now drives a car, works in her garden and looks after her home.

(3) *A girl* 16 *years of age.* This girl had double congenital deformity of the legs and had never walked, but managed to move about the house on her buttocks and hands. The X-ray report was as follows :—

> " *Pelvis :* Well developed, but of the android type.
>
> *Hips :* Congenital dislocation on both sides, and on the right side the head of the femur is separate from the shaft.
>
> *Legs :* On the right side the femur is very imperfectly developed, with a very short and thin diaphysis and the head developed separately from it : the parts below the knee-joint are all very rudimentary. The left shows a fairly well developed femur and tibia, but absent fibula."

The left leg was about 12 ins. long, with a femur of about 7 ins. There was a tibia of a few inches in length but no fibula and no knee joint; the tibia being attached to the femur by fibrous union. The foot had 3 inner toes. The right leg was 6 inches long, measured from the great trochanter. The tibia, fibula, ankle bones and those of the foot, were all mixed together in an indescribable mass which was attached to the end of the femur by fibrous union. This mass, together with 4 in. of femur,

was removed by operation to permit a metal tilting-table leg to be fitted. No operation was considered necessary for the left leg. A special appliance was devised for it with artificial knee, shin, and foot (Figs. 25 and 26).

This girl, as in the previous case, had never walked, and had to be taught balance by walking within two parallel rails. After some weeks of this training she was able to leave the rails and walk out of doors, with sticks. Her height, standing, is now five feet one inch. She was fitted in February, 1938, and in April of that year a letter was received from which the following is an extract :—

> " . . . is doing very well; taking her off the ground has given a fresh outlook on life. She is becoming more independent and grown up . . ."

She will shortly be trained in some occupation.

This patient was sent to Roehampton from Leeds by Reginald Broomhead who operated on the right leg and who gives a full description of the case in the " British Medical Journal " dated December 24th, 1938.

Other examples could be given, but these are sufficient to indicate that most of these cases can be made useful members of society, provided funds are available for the supply of limbs.

PART II—UPPER EXTREMITIES.

16.—SOME MODERN PROSTHESES FOR AMPUTATIONS OF THE UPPER EXTREMITY.

If it be true that "necessity is the mother of invention" an illustration of that truth is to be found in the attempt, on the part of man, to design an efficient prosthesis which will act as a substitute to replace the lost functions due to amputations of the upper extremity.

For 500 years or more we have a written record of such an attempt, and the experiment itself must surely go back for thousands of years, but it would appear that he has been attempting the impossible for, despite his most skilful ingenuity and industry, he has failed so far to invent a prosthesis that approximates in form and function to the natural arm. To those familiar with this problem the reasons for his failure are obvious. In the science or art of artificial-limb construction it is fully recognized, and freely admitted, that it is a much more difficult task to provide an efficient prosthesis for stumps of the upper extremity than it is for amputations of the lower limb. The functions of the latter are principally locomotion and weight bearing, while those of the former include intricate movements of flexion and extension, abduction and adduction, pronation and supination. When we consider the structure and functional value of this organ of prehension, so delicate in anatomical design, so refined and perfect in co-ordination of muscle and nerve, so sensitive in tactile sensation and capable of the most perfect gradation in the adjustment of grasp, it is not surprising that the functional value of prostheses for amputations of the lower limb is greater than of those designed for amputation of the upper extremity.

Owing to the present high standard of mechanical efficiency in the design and construction of artificial legs, the lost functions of locomotion and weight bearing are comparatively easy to restore. The leg amputee soon learns to discard his crutches and walk. Some indeed walk so well that their disability is not always easy to recognize, nor in many cases is it much of a handicap. Their industrial and economic efficiency is comparatively unimpaired, but to the arm amputee, in spite of the most recent improvements in arm prostheses, the lost functions of the natural arm and hand are never fully restored, and industrially their efficiency is definitely sub-normal. However, in spite of the difficulties and handicaps confronting the arm amputee his condition is by no means hopeless. To-day we have a range of prostheses for amputations of the upper extremity which, when accurately fitted to ideal stumps, enable the amputee to resume his vocational tasks and recreational life with a surprising measure of success. Throughout the country there are many thousands of men fitted with these latest types of artificial arms and appliances who are engaged in various forms of manual labour. Many are in agricultural work, some are at work in our coal mines and quarries, others in the

building trade and at the bench, in factories and in foundries, in offices and stores, as well as in many of the professions. In competition with other men, who have suffered no such loss, these arm amputees, by the aid of their various appliances, are back again on the pay-roll as self-supporting citizens.

It is proposed to describe here as briefly as possible some of the many factors which make the wearing of an artificial arm not only possible but successful. The principal factors are :—

A. Surgical.
B. Mechanical.
C. Instruction in the use of the prosthesis.

By discussing the subject in this order we have the advantage of considering in sequence, the principal aspects of the problem, and the essential need for the closest co-operation between those chiefly concerned with its solution, *i.e.*, the surgeon who fashions the stump, the mechanic who designs the prosthesis, those responsible for its supply, and the patient who is to use it.

(A) The Surgical Aspects.

Ideal stumps.—In dealing with the surgical aspect of the subject it should be clearly understood from the outset that we are considering chiefly only those amputations where the surgeon has a free choice of the site of election for the level of bone section. Emergency amputations—amputations due to sepsis or any other infection—are definitely excluded. It should also be clearly understood that the observations about to be made are dictated solely by prosthetic considerations. From this point of view the functional value of stumps of the upper extremity is essentially determined by certain surgical requirements of which the principal are :—

(i) The length of bone below the last joint;
(ii) The mobility of the joints above the level of bone section;
(iii) The muscular power necessary to actuate and control the prosthesis;
(iv) The position of the scar;
(v) The nature of the flaps;
(vi) Freedom from pain on pressure;
(vii) Sound healing.

Prior to the Great War, in amputations of the upper extremity, the general rule was to make the level of bone section as low as possible. Little regard was paid to the nature of the flaps, or the position of the scar, although it affects the condition of the stump and its power to withstand pressure when making use of the prosthesis. Surgical considerations alone appear to have determined the technique of the amputation. The stump being regarded principally as a lever, it seemed logical enough to leave it as long as possible, the theory being, the longer the stump the better it must necessarily be. Post-war experience, however, (based on the examination of many thousands of stumps of the upper extremity), together with the functional value of mechanical improvements in arm prostheses, is sufficiently convincing that there are considerable disadvantages in making the level of bone section as low as possible. Stumps that are too long, either above the elbow, or below the elbow, give rise to considerable difficulties and, sooner or later, show signs of deterioration,

since they are predisposed to circulatory disturbances—impaired vascularity—and the scar tissue does not easily withstand pressure due to friction from contact with the prosthesis.

Prostheses.—From the prosthetic point of view the difficulties of such stumps are even greater. In the latest types of artificial arms for above-elbow amputations there is housed internally at the distal end of the socket a mechanical movement which greatly enhances the functional value of the prosthesis. This mechanism includes (*a*) a lateral movement by which the amputee is able to rotate the forearm across the front of the body; and (*b*) an elbow-locking mechanism which enables the amputee automatically to lock the elbow joints in various positions of flexion and extension. The space required to house this mechanism is at least $2\frac{1}{2}$ ins. above the elbow joint, and, therefore, to permit its inclusion, the ideal level of bone-section should be not less than $2\frac{1}{2}$ ins. above the epicondyle —3 ins. would be even better. For amputations below the elbow the level of bone section should be $2\frac{1}{2}$ ins. above the styloid process of the una. This length of forearm stump permits of a rotary wrist mechanism being housed at the distal end of the forearm socket. These lengths of stumps are perfectly adequate for leverage and give ample muscular power to control and actuate the prosthesis. The stump should be conical in shape with a covering at the bone end of healthy skin, but it should be free from any redundant tissue.

Pressure and leverage.—With regard to the position of the scar and the nature of the flaps, while it is true that the arm stump when fitted to the prosthesis is not subjected to the same piston action as is the case with stumps of the lower extremity, nevertheless the arm stump is subjected to pressure in other directions.

In using an artificial arm, particularly one designed for manual labour, the questions of leverage and pressure play an important part. In the movements of the stump within the socket, especially when heavy loads have to be lifted, or work held down on the bench, the pressure is upwards and downwards and lateral. It will readily be seen, therefore, that the ideal position for the scar should be terminal and transverse, with equal anterior and posterior flaps. This position places the scar well out of the way of pressure by the socket. The scar tissue should be freely movable, for adherent scars are a source of trouble. Guillotine amputations should be avoided wherever possible, as their scar tissue is invariably adherent, and the periphery of the lower end of the stump is often painful and does not easily withstand pressure.

Functional value of the stump.—It cannot be too strongly emphasized that the functional value of the stump is very largely determined by the mobility of the joints above the level of bone section. Anything in the nature of ankylosis, or sub-normal range of movement, very seriously impairs the efficiency of the prosthesis. The movements by which the artificial arm and appliances are controlled and actuated, i.e. the flexion and extension of the forearm; the locking and unlocking of the elbow joint; the opening and closing of the fingers and thumb; as well as the use of the various appliances constructed for the function of grasp, are all dependent on the free and full use of the joints, particularly the shoulder joint. It is of the utmost importance that, as soon as reasonably possible after amputation, the patient should be encouraged to move the joints above the level of bone section.

Time for fitting of prosthesis.—In this connection it is to be emphasized that as soon as the scar is healed and the stump free from pain on pressure, the fitting of the prosthesis should be commenced, since wearing the arm will, as much as anything else, contribute materially to maintaining the free and full movement of the joints. Moreover, by getting the amputee accustomed, at the earliest possible moment, to the movements and advantages of his artificial arm he is less inclined to rely too much on the use of his sound hand. It also helps to diminish the feeling of inferiority—" I am a one-armed man "—which is all too prevalent. Even at the risk of having to refit or renew the socket earlier than would otherwise be necessary, the fitting of the prosthesis should be begun without undue delay.

Painful stumps.—One of the most distressing features we have to contend with in stumps of the upper extremity is the presence of persistent pain. The source of this pain is not always easy to trace, and in a large number of cases resection of the nerves does not cure the complaint.

If the source of this pain is traced to the bone end of the stump, relief is often obtained by stripping back the periosteum, digging out a little of the medulla and plugging the cavity with wax. While this is being done the rough ends of the bone should be smoothed. Spur formation is another source of trouble due to lateral pressure of the socket. The source of persistent pain in stumps is often central. If this is so a special approach is indicated. Among other things the amputee should be encouraged to try wearing his limb. Many cases of this kind have reacted successfully to the experiment ; the pain has vanished with the obsession.

Sites of amputations of the upper extremity other than the ideal and types of prostheses.—Consideration must now be given to those other amputations of the upper extremity which, from a limb fitting point of view, cannot be regarded as ideal but which, nevertheless, can be fitted with suitable prostheses of varying functional value. These are :—

(1) The forequarter amputation.
(2) Disarticulation at the shoulder joint.
(3) Short upper arm stump.
(4) Long upper arm stump.
(5) Disarticulation at the elbow.
(6) Short forearm stump.
(7) Long forearm stump and disarticulation at the wrist.
(8) Amputations below the wrist joint, i.e. from the carpo-metacarpal joints downwards.

(1) *The forequarter amputation.*—Fortunately, this type of amputation is rare. Some of those who have suffered from it have been fitted with a very light type of prosthesis. This has no functional value; it does, however, offer protection to the amputation side and helps to maintain the symmetry of the shoulders and from this point of view the value of this appliance should not be underrated. To some amputees, even to look normal in their appearance changes their whole mental attitude and outlook. The appliance is secured to the trunk by means of a linen or leather waistcoat.

(2) *Disarticulation at the shoulder joint.*—It is sometimes said that artificial arms for this site of amputation are more ornamental than useful. That, however, is no argument for withholding them from the

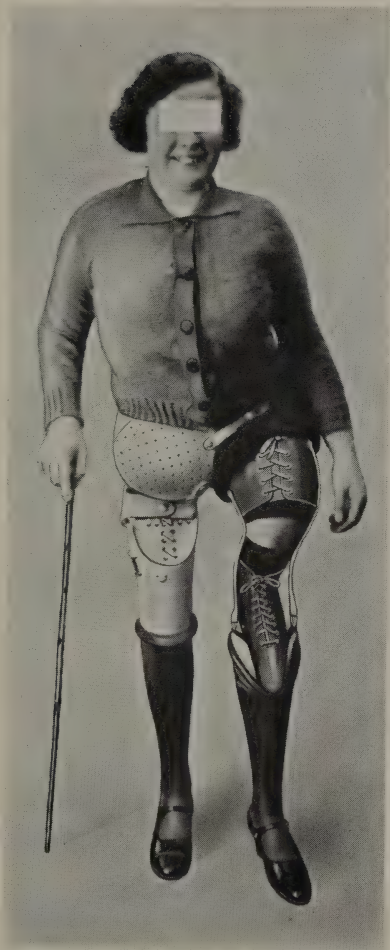

FIG. 25.—Tilting-table Limb on the right side and Special Limb Appliance on the left side.

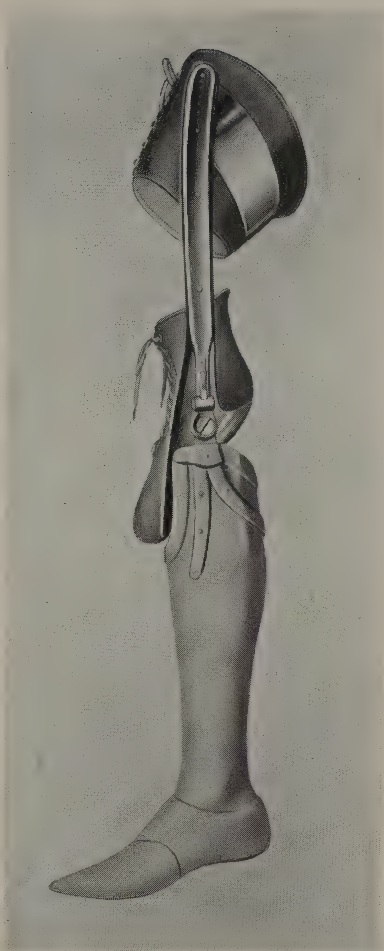

FIG. 26.—Special Limb Appliance.

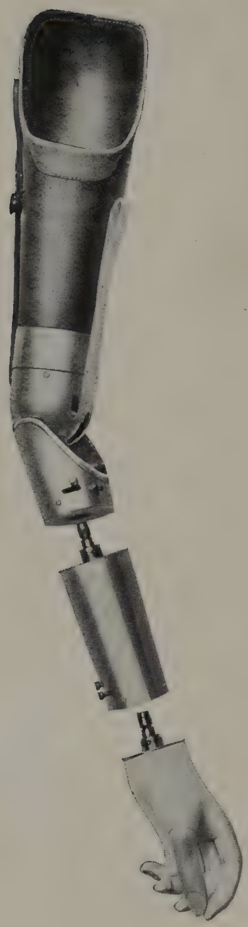

FIG. 27.—Dress Hand. Design I.

Fig. 28.—Dress Hand. Design II.

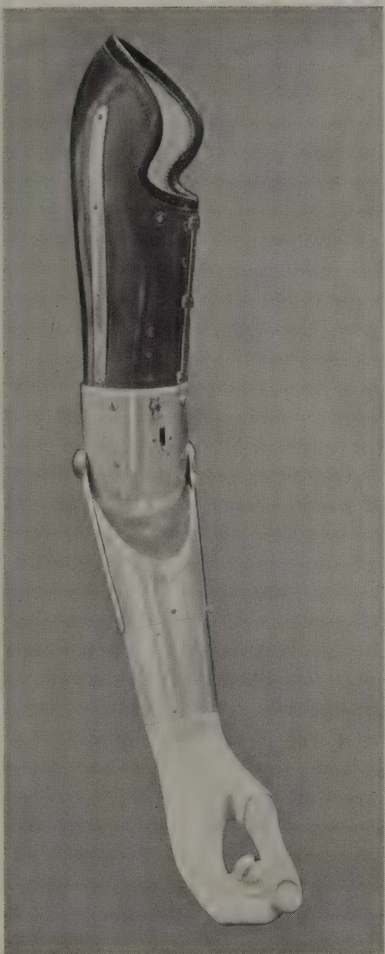

Fig. 29.—Dress Hand. Design III.

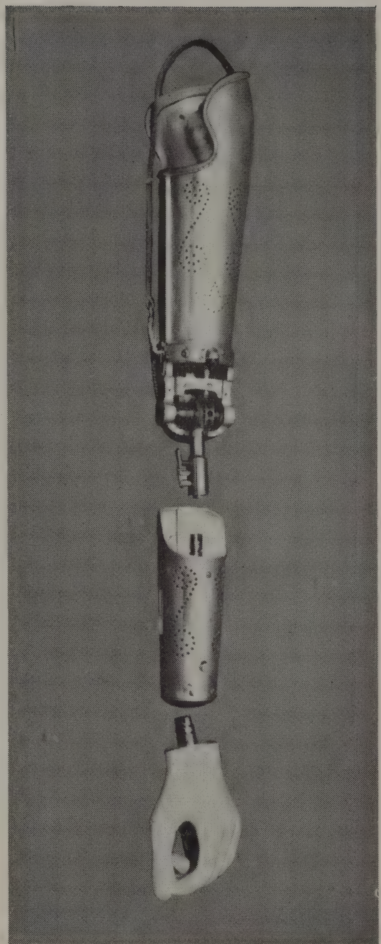

Fig. 30.—Dress Hand. Design IV.

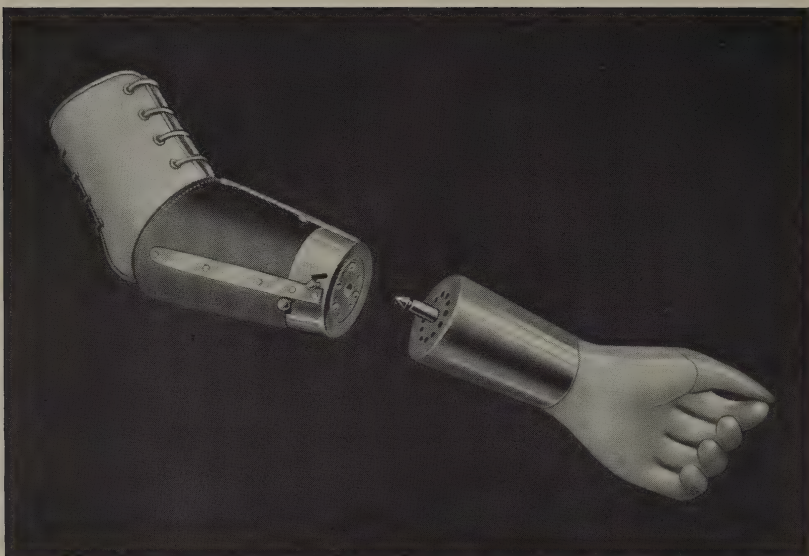

FIG. 31.—Artificial Arm for short fore-arm stump.

amputee. As a matter of fact, quite a number of men have been fitted with a through-shoulder type of prosthesis, and are making splendid use of it at many forms of manual labour. Its utility, however, depends very largely on the will of the wearer. In those cases where it is used the earning capacity of the amputee is definitely enhanced.

If a prosthesis for manual labour is not desired, an alternative for dress purposes, which is considerably lighter, is available, and amputees should be encouraged to make use of it for it restores the rounded appearance of the shoulder and protects the scar and prominent bones of the shoulder girdle. [The prosthesis for this and other amputations will be more fully described in later pages on the general classification of artificial arms and appliances.] All that need be said for the moment is that the principal part of the prosthesis for disarticulation at the shoulder is the *shoulder cap*. This may be either of leather, metal or certalmid. The cap is blocked on a cast and fitted accurately to the upper portion of the shoulder, including the clavicle anteriorly, and the spine of the scapula posteriorly. It is secured to the trunk by means of appendages. To this shoulder cap is attached, by means of a swivel or hinge joint, the upper arm socket, the forearm and the hand. The functional value of the prosthesis is increased if the scar is positioned vertically in the sub-acromion cavity, well out of the way of pressure by the shoulder cap. The axillary nerves should be free from pain, and the chest wall healthy and sound. (The upper end, or head, of the humerus should, if possible, be preserved intact, as it affords an ideal anchorage for the fitting of the prosthesis, and makes it easier to preserve the symmetry of the shoulders.)

Where circumstances arise making it impossible for a through-shoulder arm to be worn, a *protective shoulder cap* should be prescribed. This is similar in construction to the cap already referred to. If made in certalmid it is exceedingly light in weight but affords the greatest protection to the shoulder.

(3) *The short upper-arm stump.*—Where the level of bone section is 5″, or less, from the tip of the acromion process no stump is available for the control or working of a prosthesis and the prosthesis designed for disarticulation at the shoulder is fitted. From the limb-fitting point of view, measurements of the stump in above-elbow amputations should be taken from the anterior fold of the axilla. If, therefore, the ordinary above-elbow artificial arm is to be worn, the minimum length of stump, measured from the inner fold of the axilla, must be between 1″ and 2″, or between 5″ and 6″, measured from the tip of the acromion process. By surgical interference it is sometimes possible to increase the length of these very short upper arm stumps by dividing and turning up the lower parts of the insertions of the pectoralis major, latissimus dorsi and teres major. It is thus possible to utilise the axilla and secure an increased measure of leverage and control over the prosthesis.

Providing the length is sufficient to control the prosthesis, the short upper-arm stump can be fitted with the type of artificial arm available for the above-elbow stump of ideal length. The socket, however, will have to be carried up a little higher so that the upper part embraces the top of the shoulder; this is equivalent to what is termed a *modified shoulder cap*.

(4) *The long upper-arm stump.*—While this may be a good stump from the surgical point of view, possessing all the necessary surgical features of the ideal stump, if the level of bone section is too low, say less than

3″ above the elbow joint or more than 9″ measured from the tip of the acromion process, its functional value is impaired because it is too long to be fitted with the ideal above-elbow artificial arm, which embodies the lateral movement mechanism and the automatic elbow-locking mechanism. The case has, therefore, to be fitted with the through-elbow type of arm which, from the mechanical point of view, as will be described later, is the least satisfactory of all.

(5) *Disarticulation at the elbow.*—Surgical opinion is by no means unanimous on disarticulation at the elbow. Some prefer disarticulation because the stump is longer, and the bulbous extremity provides a projection for the fitting of the artificial limb, whilst others, for the same reason, object.

A surgical objection to disarticulation at the elbow is the difficulty of finding suitable flaps. The stump also suffers from hypersensitivity, adherent scar tissue, and impaired vascularity. The prosthesis available for this type of stump is, as already stated, mechanically the weakest and least satisfactory of all. To accommodate the stump the socket has to be slit anteriorly. The axes of the side steels have to be fixed at a level lower than that of the natural elbow joint. The position of the elbow lock must be lateral and external instead of central and internal, and because of the bulbous extremity at the lower end of the socket it is difficult to get the best use of the forearm when flexed at right angles. For these reasons disarticulation at the elbow should be avoided whenever possible.

(6) *Short forearm stump.*—This site of amputation is indeed a " bone of contention." Many surgeons are of the opinion that anything less than 4″ of ulna is of no orthopædic value and prefer disarticulation at the elbow, or very low amputation of the upper arm; but if it were possible for those who hold this view to see for themselves how much can be accomplished in the way of manual labour by amputees with stumps of 4″, or even less, when fitted with the right type of prosthesis, they would undoubtedly revise their opinion of the functional value of these very short forearm stumps. Owing to the insertions of the biceps, triceps and brachialis anticus, a considerable amount of muscular power is available at this site of amputation, and, when properly harnessed and transferred to a prosthesis of the following design, the unimpaired capacity of this powerful group of muscles provides a stump, the functional value of which is out of all proportion to its length.

The type of prosthesis which is best suited for this short forearm stump and which can be recommended with every confidence, consists of (*a*) an inner cup socket of soft leather moulded from a carefully-taken cast of the stump; (*b*) an outer blocked leather socket of the best butt hide: this outer blocked leather socket acts as a container for the inner cup socket, the latter being stitched within the outer socket; (*c*) a soft leather arm corset in two sections shaped at an angle of about 35° of flexion, the anterior and posterior edges being eyeleted for the purpose of lacing the corset round the condyles of the humerus; (*d*) a bisected forearm; (*e*) a rotary type of wrist mechanism; (*f*) a dress hand.

With regard to the inner cup socket, the more closely and accurately it fits the short stump the less motion will be lost. A loose or ill-fitting socket means loss of control over the prosthesis, and loss of control means a loss of power. In bisecting the outer socket about 2½″ below the lower end of the stump, ample room is available for the housing of the wrist mechanism. The value of this bisection of the forearm is that it enables

the amputee to wear his appliances as near as possible to his own motor power. The lower section of the forearm and hand, which articulates with the upper forearm section, is used for dress purposes. Thus we have a combination of a working arm and a dress arm.

For some forms of manual labour, particularly where heavy loads have to be lifted, the addition of detachable appendages is of considerable value. These are easily attached to the socket by riveting two metal lugs, one on either side of the upper part of the prosthesis. The appendages help to take the strain from the condylar region of the upper arm and distribute it across the back of the shoulders. While the slight degree of permanent flexion necessitated by this type of corset prevents full and free flexion and extension of the prosthesis, this disadvantage is more than compensated by the security of the stump in the socket. For short forearm stumps, both for manual labour and dress purposes, this is a most efficient type of prosthesis. It is extremely simple, but exceedingly effective and quite inexpensive. It can be recommended with the utmost confidence.

(7) *Long forearm stump and amputation at the wrist.*—These sites of amputation have all the disadvantages, both surgical and mechanical, already mentioned in connection with the very long above-elbow stumps. Surgically they are predisposed to circulatory defects, malnutrition of the skin, and do not take kindly to pressure when fitted with a prosthesis.

It is claimed that amputations at these sites preserve pronation and supination. These movements, however, are not always preserved. Sometimes the loss is due to surgical causes, such as bony or fibrous union of the ends of the bones. At other times the loss is due to the socket which, in the case of disarticulation, almost invariably has to be slit anteriorly to accommodate the bulbous extremity. When the socket fits too tightly the movements of pronation and supination are lost; when it fits too loosely the stump rotates within the socket and these movements are quite impossible. Where however both hands have to be amputated, disarticulation at the wrist is to be preferred: what some of these cases can do with the assistance of their artificial hands and appliances is indeed amazing, but some actions are nevertheless best performed by their own stumps.

(8) *Amputations below the wrist joint,* i.e., *at or below the carpo-metacarpal joints.*—Owing to tender scar tissue, stumps beyond the carpo-metacarpal joints are exceedingly difficult to fit. However, where there is freedom from tenderness and pain on pressure, it is possible to provide a prosthesis either for manual labour or purely aesthetic purposes. In many cases it is preferable not to issue an appliance at all but to leave the stump as it is, because any part of the end retaining sensitivity is of infinitely greater value than the most perfect artificial appliance ever invented. If the thumb remains intact a useful opposition appliance can be fitted to replace the lost digits. In the palm of this appliance a threated metal nipple can be fitted which will enable the amputee to make use of various appliances for manual labour.

Cineplastic amputations.—A brief reference must be made here to cineplastic amputations introduced by Dr. Vanghetti, and made popular by Professor Putti, and during the war, and for a few years subsequently, enthusiastically advocated in many quarters in this and other countries. One operation consisted of separating the opposing flexor and extensor muscles or tendons, together with a portion of the bone to which they are attached, in order to make club-shaped extremities, and covering

them with skin and sub-cutaneous tissue. In another operation a tunnel was made through the muscle or tendon, the tunnel being lined with skin. If the tunnel is too small to allow for proper ventilation the skin becomes unhealthy and takes on the appearance of mucous membrane. To the club end was fixed a metal ring. An ivory bar was passed through the tunnel. Attached to these were the control cords of the prosthesis. By contracting the muscles of the cinematized stump, tension was placed on the control cords, which pulled against the resistance springs of the mechanical hand. By means of this movement flexion and extension of the fingers was obtained.

In the early days those who were associated with the operation were very hopeful that by harnessing this muscular power and utilising it for manipulating the prosthesis, the lost functions of grasp would be restored in a greater measure than ever before. Unfortunately we were soon disillusioned. The limited range of muscular contraction, together with the lack of a suitable prosthesis, nullified the theoretical value of the operation. Theoretically the idea is brilliant, but as its final success depends so much on designing a suitable mechanical hand, until that is forthcoming, no useful purpose can be served by continuing the experiment. For identical reasons the operation has fallen into disuse in this and other countries.

(B) Mechanical Factors and Classification of Artificial Arms for Amputations of the Upper Extremities.

General considerations.—The surgical features that help to determine the functional value of stumps of the upper extremity have already been emphasized. Consideration must now be given to some mechanical factors that determine the practical utility of the prosthesis with which the stump is fitted.

In the design and construction of arm prostheses the following features are essential, and should be constantly borne in mind: (1) Simplicity, (2) Strength, (3) Lightness and (4) Utility.

Owing to the nature of the disability and the patient's mental attitude toward it, the mechanism of the artificial arm should not be too intricate, or difficult to control. If it is, the arm amputee will soon get discouraged, and the prosthesis will probably be discarded before it is given fair trial. From the point of view of practical utility the more simple the mechanism is, the more effectively it functions.

If designed for manual labour the artificial arm, without being unduly heavy, should be sufficiently strong for ordinary fair wear and tear. The weight factor is important, for experience has proved that through excessive weight the efficiency of arm prostheses has been definitely impaired. Mechanical improvements should always be encouraged and, when of undoubted value, should be embodied in the manufacture, but care should be taken that they do not add unduly to the weight. This is a point that requires careful and constant scrutiny. Wherever possible more use should be made of the best aluminium alloys. This metal is light, but very strong, and eminently suitable for housing the bearings, both at the elbow and the wrist, where strength and lightness are so important.

In this connection the use of certalmid (pp. 12, 38 and 73) should also be mentioned. Certalmid is a casein compound supplied in the form of powder.

When mixed with water it turns into a thick creamy glutinous paste which sets very hard, and is most tenacious and durable. By using successive layers of muslin saturated with this solution light and strong sockets can be made and also artificial hands for dress purposes. The sockets are moulded on a cast of the stump—wax moulds are used for the construction of the hand. Care must be taken to see that the solution percolates through each layer, otherwise the laminations will separate. In many instances certalmid can replace metal, leather, and wood parts used in the construction of arm prostheses. It is sufficiently hard to be cut for fitting adjustments; it can be drilled for ventilation and tinted flesh colour, and, when waterproofed, it is practically impervious to moisture.

Ultimately, the value of artificial arms is determined by their practical efficiency. In form they should not only resemble the natural arm and hand but also, as far as is mechanically possible, assist in restoring their lost functions. In prescribing an artificial arm it is essential to ascertain from the amputee the purposes for which the arm is required, the kind of work at which he is employed, and the uses to which the arm is likely to be put. This information will help to determine not only the most suitable type of limb to be prescribed but also the nature and number of the appliances to be issued.

Further, the amputee's general mental and physical ability must be taken into consideration and, in general, unless there are good grounds for prescribing artificial arms with complicated mechanism, the less intricate types will probably be more suitable.

The classification of artificial arms.—In order to facilitate the administration necessary in connection with the supply, and to give some guidance regarding the most suitable types, artificial arms are classified as follows, the sites of amputation being indicated alphabetically and the uses for which the prosthesis is required numerically.

The letter A. indicates—disarticulation at the shoulder, or stumps of insufficient length to control an upper arm prosthesis.
,, B. ,, —short upper-arm stumps.
,, C. ,, —the ideal length of above-elbow stump.
,, D. ,, —disarticulation at the elbow. D. also denotes stumps that are too long to be fitted with the C. type of arm, and also stumps that are too short to be fitted with an E. type of arm.
,, E. ,, —short forearm stumps.
,, F. ,, —the ideal length of forearm stump.
,, G. ,, —disarticulation at the wrist and also those forearm stumps that are too long to be fitted with the F. type of arm.

The numbers 1, 2 and 3 are used, respectively, for the arm for heavy work, the arm for light work and the light dress arm.

For instance, if a patient with a disarticulation at the shoulder requires an artificial arm for dress purposes, the A.3 type would be prescribed. If, on the other hand, the patient had a good above-elbow stump—say $2\frac{1}{2}$ inches above the epicondyle—and required an artificial arm for heavy manual labour, other things being equal, a C.1 type would be prescribed as being the most suitable. If, however, a patient had a similar ideal length of stump but was employed as a clerk or a draughtsman, a C.1

type would probably be too heavy for his requirements; in that case a C.2 or a C.3 type would be more suitable.

So long as it is understood that artificial arms are available for the various sites of amputation mentioned, either for heavy manual labour, light work or dress purposes, it is not necessary to adhere rigidly to the above classification.

The mechanical basis of some representative types of arm prostheses.—About thirty different types of artificial arms are supplied by the British Ministry of Pensions, but a complete description of each is unnecessary. There are several minor variations among them—and a few major ones—but the fundamental principles of construction are common to all. A brief general description will, therefore, be given of the principal component parts of the mechanism used in the construction of an artificial arm, with some indication of how, by means of appendages, the muscular power of the trunk and shoulders is utilised to induce the movements of flexion and extension of the forearm and hand, and the locking and unlocking of the elbow joints, etc.

For amputations above the elbow where the length of stump is not less than 2½ ins. above the elbow joint, there are types of prostheses which are eminently suitable and of the greatest practical efficiency. They embody the latest improvements and are available for heavy manual labour, light work and dress purposes. Their principal components are :—

(1) The appendages.
(2) The socket.
(3) The lateral movement mechanism.
(4) The elbow-locking mechanism.
(5) The bisected forearm.
(6) The rotary wrist mechanism.
(7) The dress hand.

(1) *The appendages.*—For all above-elbow artificial arms appendages are necessary. They are the means by which the prosthesis is securely attached to the stump. They also provide the muscular substitutes or artificial tendons which utilise the powerful muscles of the shoulder and trunk to lock and unlock the elbow joints, flex and extend the forearm, open and close the fingers and thumb, and manipulate the other appliances designed to restore the lost functions of grasp.

These appendages are made either of webbing or leather or a combination of both. The main section passes from the socket across the shoulders and under the axilla on the opposite side of the body. The axilla portion is suitably padded with sponge rubber or felt. From the axilla the main section is continued up and over the shoulder on the amputated side, and connected by a leather thong to the lifting lever of the elbow-locking mechanism. The addition of a short section of rigid webbing in front, and of elastic webbing at the back, embraces the shoulder and keeps the socket securely in position on the stump. The ends of these sections are fixed to the socket by tubular rivets. The flexion webbing by which the forearm is raised is made adjustable by the addition of a neat metal slide which passes across the back, and is connected with the flexion thong which passes through a floating pulley on the socket to an external lever on the forearm. The external lever fitted on the forearm is formed with a rigid ring at the end through which the thong passes. At the end of the thong a small ring is fitted which acts as an anchorage when flexing and, by

running freely through the rigid ring of the lever, it can be connected up to any appliance designed to give the function of grasp, e.g., split hooks (Fig. 36), etc.

(2) *The socket.*—The socket is made either of metal, leather or certalmid, and moulded on a cast of the stump. It should be suitably perforated for ventilation.

The fit of the socket is important: the suggestion sometimes made that the fit of a socket for stumps of the upper extremity is not so important as in stumps of the lower limb is very misleading and might easily result in carelessness in fitting and manufacture. While the arm stump may not be subjected to weight bearing and piston action, it is definitely subjected to pressure and, at some forms of manual labour, very severe pressure. The function of the stump in the socket is to act as a lever; therefore it clearly follows that, in the act of levering, the more accurately the socket fits the stump the less lost motion there will be, and the more control the amputee will have over the prosthesis. If the socket is ill-fitting—if it is too loose or badly aligned—torsion and tilting of the stump takes place, and this often leads to painful abrasions. By a more general use of the slip socket in all arm prostheses a better fit will be obtained.

(3) *The lateral movement mechanism.*—This consists of :—(*a*) two alloy ring castings; (*b*) a steel segment and spring; (*c*) a locking nut and wing bolt.

The main casting is grooved and slotted to take the metal ring and steel segment. The spring engages the grooves on the steel segment. The main casting is riveted to the lower end of the socket; and the elbow cup being fixed to the ring and segment allows the one section to rotate freely on the other. The advantage of the lateral movement mechanism is that it allows the forearm to be rotated across the front of the body.

(4) *The elbow-locking mechanism.*—The elbow-locking mechanism consists of a metal dome, or spun cup, which houses the main frame work or chassis. The chassis is an alloy casting, circular in shape, with depending lugs or ribs which act as supports for the various operating parts of the locking device. Centrally and transversely is the main steel shaft or spindle, running in brass bushes fitted to the main casting. The centre of the shaft is cut square to take the locking arc. It is also squared at each end to take the elbow steels which carry the forearm section. The components are :—

> (*a*) the locking arc; (*b*) the plunger barrel; (*c*) the plunger bolt and striking pin fixed at right angles to the plunger bolt; (*d*) the drum; (*e*) the cam and pawl; (*f*) the pinion or toothed wheel; (*g*) the rack and lifting lever; (*h*) the control springs.

The method by which the forearm is locked in the various positions between extension and flexion is as follows.

By a downward pressure of the stump in the socket, together with a backward movement of the arm and shoulders, tension is placed on the locking strap which is attached at one end to the appendages, and at the other end to the lifting lever which projects in front of the elbow dome or spun cup. Presuming the elbow lock to be in the neutral position, the downward pressure of the stump in the socket tightens the control cord and raises the lifting lever, to which a toothed rack is connected by a movable link. In raising, the lifting lever engages the toothed rack with the toothed wheel which revolves the drum and cam.

A striking pin, fixed at right angles to the plunger bolt, travels over the undulated face of the cam. The plunger bolt is controlled by a compression spring and when the striking pin travels *down* the slope of the undulation and reaches the lowest point, the bolt is thrust forward by the compression spring into a hole in the locking arc, which is fixed to the main elbow shaft or spindle. The elbow joint is now locked and the tension on the locking strap being released, the spring controlling the lifting lever and rack comes into operation. By means of a free-wheel movement in the drum, controlled by the pawl and spring, the downward movement of the lifting lever, in conjunction with the rack, causes the toothed wheel on the bolt shaft to travel in the opposite direction without disturbing the position of the cam. When tension is again placed on the locking strap the lifting lever is raised, and the striking pin on the plunger bolt travels *up* the slope of the undulation on the cam face. This movement withdraws the plunger bolt from the locking arc. When the crown of the undulation is reached the striking pin engages a small groove and is held there by the tension of the compression spring in the plunger barrel, and the lock is now back in the neutral position.

(5) *The bisected forearm.*—The forearm is constructed of metal or certalmid and is bisected to permit detachment of part of the forearm and hand, and the substitution of a working tool or appliance; this enables the amputee to use his appliances as near as possible to his own motor power in the stump. The upper-forearm section carries the side steels which fit on to the square ends of the elbow bolt or spindle, thereby connecting the upper and lower segments of the prosthesis.

(6) *The rotary wrist mechanism.*—At the lower end of the upper-forearm piece is housed the rotary mechanism consisting of: (*a*) the main casting; (*b*) a steel snap-catch blade; (*c*) a steel locking-bolt and spring; (*d*) three steel balls and springs; (*e*) two ball-headed pins.

The main casting is circular in shape with four lateral columns or pillars and one central pillar. The central pillar is drilled to take a brass bush, which is slotted to receive the snap-catch blade. Three of the other pillars are placed equidistant in triangular formation and drilled to house the spring-pressed balls. The fifth pillar houses the locking-bolt and spring. All are held in position by means of a face plate, which is screwed to the main casting.

Mounted on the upper end of the lower forearm section is another casting covered with a perforated face plate, in the centre of which is a slotted steel stem. The lower forearm section articulates with the upper forearm section, both being securely held by means of the snap-catch blade articulating with the slotted steel stem.

(7) *The dress hand.*—The dress hand is attached to the lower forearm section by means of a screwed spindle which runs centrally through the lower forearm piece. At one end the spindle is fixed to a casting in the wrist piece of the hand, and at the other end it is fixed to the stem of the face plate. Rotation of the lower forearm section and the hand is voluntary, but very easy, owing to the spring-loaded steel balls on the face plate of the upper forearm piece. By means of the perforations on the face-plate of the lower forearm piece the forearm and hand can be fixed in various positions by releasing the locking bolt which is positioned at the lower end of the upper forearm section.

In addition to the design just mentioned there are several others equally

suitable for amputations above the elbow. Their component parts are as follows :—

Design I (*Fig.* 27)—

(i) Moulded leather socket.

(ii) Lateral movement mechanism.

(iii) Elbow dome or spun cup, which houses—

(iv) The automatic elbow-locking mechanism, consisting of elbow bolt with greasing device, locking arc and forearm stem in one-piece forging, flexion arc, cam, clutch, return spring, locking plunger and spring, locking lever, forearm piece, rotary wrist mechanism, dress hand.

Design II (*Fig.* 28)—

(i) Upper arm socket, of leather or duralumin.

(ii) Elbow-locking mechanism, comprising metal dome, side steels, elbow spindle, quadrant and screw, barrel piece, plunger, plunger spring, operating lever, connecting link, snap-catch and spring, metal collar and dove tail core.

The above parts are for the hand-operated type of elbow lock. In the automatic type of elbow lock there is, in addition, a cotter lever with spring and nut; operating lever with spring and pin; pulley frame with double pulleys.

(iii) Forearm piece with rotary wrist mechanism; the hand for this design may be made of rubber, certalmid or wood.

Design III (Fig. 29)—

(i) Moulded leather socket, reinforced by steels.

(ii) A lateral movement mechanism, comprising two alloy castings, a steel segment and spring, a locking bolt and wing nut.

(iii) The elbow-locking mechanism, comprising the locking arc, the plunger barrel, plunger, drum, cam and pawl, pinion or toothed wheel, rack and lifting lever, control springs.

(iv) The forearm, made of metal or certalmid, and bisected. The upper portion of the bisection is fitted with side steels and connected to the elbow spindle or shaft. At the lower end of the bisection is housed the rotary wrist mechanism, comprising metal casting, snap-catch blade, locking bolt and compression spring, three steel balls and springs, two ball-headed pins.

(v) Lower forearm piece and dress hand.

Design IV (*Fig.* 30)—

(i) Upper arm duralumin socket.

(ii) Elbow-locking mechanism, comprising T-piece, which includes elbow bolt and stem to which the forearm piece is attached, 2 bronze bushes, 2 steel balls, a locking plunger and locking lever, and tension spring.

(iii) Bisected forearm and dress hand.

Artificial arms for disarticulation at the shoulder, etc.—*Type A*.1. The principal component parts of all the different patterns of this type are as follows :—(1) the shoulder cap; (2) the upper arm section; (3) the elbow-locking mechanism; (4) the forearm section; (5) the rotary wrist mechanism; (6) the dress hand.

The shoulder cap is made either of leather, duralumin or certalmid, It is moulded to a cast so that it fits accurately the site of amputation care being taken to see that there is no pressure of the cap on scar tissue. To this shoulder cap is attached, by means of a swivel or hinged joint, the ordinary upper arm, forearm and hand. The shoulder joint, which is usually positioned about 1 in. below the head of the humerus, gives a limited degree of flexion and extension, of abduction and adduction. The upper arm section is made of leather, certalmid or duralumin. At the lower end, in an elbow dome or spun cup, is housed the elbow-locking mechanism. In some types a rotary-movement mechanism is situated between the lower end of the upper arm socket and the elbow dome. The elbow-locking mechanism comprises a semi-circular alloy casting, with elbow spindle and locking arc, etc.

The forearm is made of leather or duralumin, and is attached to the elbow dome or spun cup by means of side steels. Centrally situated in the forearm section is a locking rod, controlled by a spring and lever. This rod articulates with the perforations on the locking arc. As a rule the elbow is locked by means of the sound hand. At the distal end of the forearm is housed the rotary-wrist mechanism, with snap-catch blade and spring. This mechanism enables the artificial hand and appliance to be rotated and released.

Types A.2 and A.3 are similar in design to A.1 but much lighter in construction.

In spite of the difficulties associated with this site of amputation, many amputees have been able to make good use of their prostheses at manual labour. Some have engaged in poultry farming, others are postmen, another is a stoker, and so on.

Artificial arms for through-elbow amputations, etc.—The type of artificial arm available for very long above elbow stumps, disarticulation at the elbow, and very short forearm stumps, is mechanically the weakest and least satisfactory of all. The principal component parts are :—(1) an adjustable leather socket; (2) exterior box-jointed side steels; (3) lateral hand operated elbow lock; (4) bisected or full length forearm; (5) certalmid, wood or rubber hand.

Owing to the bulbous extremity of the stump, the socket has to be slit anteriorly in order to accommodate the enlarged lower end. The box-jointed side steels and lateral elbow lock have to be riveted to each side of the already bulky socket, thereby making it more bulky.

On flexion of the forearm the lower end of the stump projects below the level of the natural elbow. This makes the prosthesis not only unsightly, but impairs its usefulness, especially at the bench or desk, as the forearm cannot be laid flat on any object that has to be held down. If the arm is required for manual labour the forearm piece should be bisected; for dress purposes the full length forearm is more suitable. The type of hand supplied is usually for dress purposes.

Artificial arms for very short forearm stumps.—Reference has already been made to the functional value of the short forearm stump when fitted with a suitable prosthesis. The secret of success lies in the construction of the socket, and the fitting of the arm corset. It is essential to have an inner cup socket moulded from a carefully taken cast of the stump. This inner cup socket should be made of soft leather and fit the stump accurately. The outer socket, which really acts as a container for the inner cup socket, should also be moulded to the cast of the stump. If the

prosthesis is required for manual labour, the forearm, whether it be made in leather or metal, should be bisected (Fig. 31.) This is very important as it allows the appliances to be used at the end of the stump.

The most useful type of corset is that known as the "Williams". It consists of two soft leather sections, shaped at an angle of 35° of flexion and stitched to the inner upper edges of the socket. The anterior and posterior edges of the corset are eyeletted so that it can be laced around the condyles of the humerus. This type of corset holds the short stump securely in the socket. An alternative to the "Williams" corset is the ordinary upper arm type with box-jointed side steels.

Where heavy loads have to be lifted appendages are essential. They take the strain off the stump and distribute it across the back of the trunk and shoulders. Literally, as well as figuratively, the back was made for the burden.

Artificial arms for the ideal forearm stumps.—For ideal below-elbow stumps the fitting and wearing of an artificial arm present no difficulties. With the use of appropriate appliances there is very little in the way of manual labour that cannot be done. For this site of amputation a wide range of prostheses is available. The amputee's occupation is the chief factor to be considered in determining the type to be supplied.

The socket may be made of metal or leather, with or without appendages. Bisection of the forearm is not essential. Leather suspension straps connecting the socket to the upper arm corset can be substituted for side steels. If the arm is required for heavy manual labour the socket can be made of duralumin, with a steel reinforcing frame and dove-tailed core at the wrist.

Artificial arms for amputations through the wrist.—Arm prostheses for disarticulation at the wrist present difficulties similar to those referred to for disarticulation at the elbow. The socket has to be made adjustable to accommodate the bulbous extremity of the stump. The length of the forearm has to be increased by $2\frac{1}{2}''$ to house the rotary sector and snap-catch mechanism at the wrist; this makes the artificial arm longer than the natural arm. An alternative type may be provided, but it is of less practical value. It has no rotary sector or snap-catch mechanism at the wrist and, from the point of view of manual labour, it is a distinct disadvantage that the hand and appliances are screwed into the wrist piece.

Mechanical hands versus appliances.—It has already been admitted that the attempt to design a mechanical hand that will restore the lost functions of the natural one is a practical impossibility; nevertheless the attempt still goes on. Some amputees, particularly among the professional classes, prefer a mechanical hand to one of the dummy type. A brief description will now be given of the three most representative designs available in this country.

(1) *Design I.*—From a mechanical point of view this is the most intricate and elaborate of all (Fig. 32.) The body of the hand is in two lateral sections with the joint in the median plane. It may be constructed of metal, bakelite or fibre. The fingers are made of sheet steel, the first and second phalanges being articulated. The mechanism which controls and actuates the finger movements is concealed in the body of the hand. The opening and closing of the fingers is obtained by means of control cords attached at one end to the shoulder appendages, and at the other end to the hand mechanism.

The essential parts of the hand consist of :—(*a*) a metal disc; (*b*) a serrated arc; (*c*) a transverse axle; (*d*) a rotary wrist mechanism; (*e*) a reversing gear; (*f*) connecting rods and control cords.

The disc revolves horizontally on a vertical axis and its edge is cut in an endless screw thread. Two control cords are wound round the disc laterally, one of which rotates it in one direction, the other in the opposite direction. Running transversely across the body of the hand is an axle, on the upper side of which are fixed the fingers, and on the lower side a serrated or toothed arc. A pull on the control cord causes the threaded disc to move the toothed arc and rotate the transverse axle. By means of pitmans, or connecting rods, this movement is transmitted to the fingers, which are locked automatically in any position between extreme flexion and extension. A steel rod, fixed at one end to the lower elbow joint, and at the other end to the rotary wrist mechanism, induces, on flexion and extension of the forearm, the movements of pronation and supination of the hand.

The practical value of this mechanical hand is determined by the site of amputation, and the mentality of the wearer. Some arm amputees complain that it is too heavy; others, with suitable stumps and sufficient will power, find it quite satisfactory.

(2) *Design II.*—From a mechanical point of view this design (Fig. 33), is very much simpler than the previous one. The hand and fingers are constructed of nickel-plated sheet metal. The body of the hand is in two sections, the palmar and dorsal. The fingers are formed in the shape of a dorsal shell, with cork insertions on their palmar surfaces to facilitate the tenacity of grasp.

The mechanism of the hand consists principally of a metal framework in the shape of an horizontal bar, with five projecting ribs between which are pivoted four fingers with coiled resistance springs. A single axle passes through each of the four fingers and coiled springs, and also the five projecting ribs. Flexion of the fingers is obtained by a pull on the flexible cable which is attached at one end to the hand mechanism, and at the other end to the shoulder appendages. When the tension is released from the control cord, the coiled resistance springs come into action and close the hand. The power of grasp is determined by the strength of the resistance springs.

While this hand is not designed for manual labour it is sometimes used for dress purposes. Owing to the wide range of opening, and the ease with which it can be accomplished, the hand is very suitable for some double-arm amputees. It enables them to feed themselves, pick up a tumbler, and drink.

(3) *Design III.*—In design and construction this is a distinct departure from all other types of mechanical hands, and is undoubtedly one of the most original contributions ever made to arm prostheses. (Fig. 34).

It is constructed of special tapered coiled springs, stitched to a backing of stout leather which forms the dorsal part of the hand. Flat strips of tempered steel are fixed within the four fingers on their dorsal side, to increase their rigidity. Flexible steel wire cables are attached at one end to the fibre finger tips, and at the other end to a T-shaped metal bridge and chain. To strengthen the power of grasp the palm of the hand is padded with soft sponge rubber covered with leather. Flexion and extension of the hand is obtained by means of a ratchet and lever fixed on the lower outer side of the forearm piece, which act in conjunction with the T-piece and flexible cables. The thumb is operated

independently of the four fingers, and is so arranged that it can be rotated to oppose each of them, or moved to the side, in order that objects can be grasped in the palm of the hand. The hand is mounted on a wooden core and fixed in an aluminium cup, thus forming a ball and socket wrist joint which, on full flexion of the hand, is automatically clamped or locked.

While this prosthesis has the appearance of a hand it is essentially a working appliance designed specifically to induce the function of grasp, and it achieves that object most successfully. It is unfortunate that when the hand is fully flexed the wrist joint is absolutely immobilised, for at some forms of manual labour this lack of movement is a decided disadvantage.

Appliances.—As far as manual labour is concerned, appliances have definitely superseded mechanical hands. The range of appliances available is very extensive and varied; indeed the chief difficulty is to select the most useful. The amputee's occupation should be the principal factor in determining the types to be supplied. The ordinary "Plain Hook" (Fig. 35) which is one of the oldest, is for most purposes one of the best. As a general utility appliance the "Split Hook" (Fig. 36) is equally useful, and for double-arm amputees its practical value is well nigh incalculable. To appreciate its real worth one has to see it in actual use. The various types of spade-grips (Fig. 37) and agricultural appliances have made it possible for large numbers of arm amputees to earn their living as market gardeners, farm workers, roadsmen and poultry farmers. Most of these appliances have a universal joint, and can be fixed to garden tools and agricultural implements. For fitters and bench-workers several types of useful tool-holders, gripping and other devices are available. (c.p. Figs. 38 to 42.)

By means of inexpensive adaptors many of the ordinary tools of skilled craftsmen and artisans, e.g., chisels, files, saws, hammers, can be fitted directly to the wrist piece of the artificial arm. Wherever possible more use should be made of this method, as it enables the amputee to make use of his own special tools.

Prostheses for double-arm amputees.—The type of prosthesis for double-arm amputees does not differ materially from those supplied to "single" cases. The appendages and control cords have frequently to be modified. The elbow-locking mechanism and gripping devices must be fully automatic. When ordinary appliances are found unsuitable others have to be designed to meet the special requirements. Indeed, double-arm amputees are in a class by themselves, and must of necessity receive special consideration. Their distressing condition, however, is not as hopeless as it would appear at first sight. By way of compensation for their irreparable loss, many develop an extraordinary degree of will-power and determination, which enables them to achieve an amazing measure of success in the use of their artificial arms and appliances. The practical value of the prosthesis is very largely determined by the site of the amputation. More effective use can be made of appliances with below-elbow stumps than with amputations above the elbow. But whether the site of amputation is above or below the elbow it is possible, after a few weeks' instruction, for most double-arm amputees to feed themselves, partly dress and undress, write, etc. Some are able to enjoy a business career, others are accountants, insurance agents, clerks,

commissionaires. Some are able to do a little light manual labour, several play golf, some ride a bicycle.

From the limb-fitting point of view double-arm amputees present tremendous difficulties, but by their courage, perseverance and determination they surmount them to an extent that is almost incredible, and while no claim can be made to a 100-per-cent. success there is no record of absolute failure.

(C) Instruction in the use of the prosthesis.

As early as 1917, owing to the large numbers of arm amputees failing to make good use of their appliances, the Government realised the need for special instruction, but, until the following year, war conditions made it impossible to provide the necessary facilities. In 1918 arm instruction schools were established: first at Charterhouse Military Hospital, then at Queen Mary's Hospital, Roehampton, and subsequently at each of the Limb Fitting Centres in the provinces. The scheme of instruction was by no means ambitious; in some respects it was the essence of simplicity, but on that account proved to be more effective. It did not aim at vocational training; its object was purely functional, being designed to teach the amputee how to understand and control the movements and mechanism of the prosthesis. The instruction was divided into two parts. The first part included stump exercises, and the second, training in the functional use of the appliance.

Although the stumps were soundly healed and free from pain, many patients, through months of inactivity since the amputation, were debilitated, and had very limited movement in the joints above the level of bone section. These stump conditions militated against the successful use of the artificial limb. The stump exercises consisted principally of the four active movements of flexion and extension, abduction and adduction. Occasionally the movements were passive.

With regard to instruction in the use of the artificial arm and appliances, the finer movements were obtained at woodwork and the coarser ones at digging in the garden, filling and wheeling barrow-loads of mould, and driving large stakes into the ground. In the workshop each man had his own bench and kit of woodworking tools. At first the articles made were chiefly paper knives and soap boxes, but later on it became possible to turn out more elaborate ware, including tea trays, small cabinets and cupboards. Each man was allowed to retain the articles he made and occasionally prizes (e.g. cigarettes, tobacco, etc.) were awarded for the best workmanship. The spirit of friendly competition and good fellowship was a delight to watch and while each man was vying with the other the real object of the instruction was being unwittingly achieved: the amputee was learning how to control the movements of the prosthesis and prove to his own satisfaction how useful it could be at the various forms of manual labour.

The instruction was given by men who were themselves arm amputees, and wearing similar appliances. This is important: the whole attitude and outlook of the amputee becomes totally different when he is instructed in the use of his appliances by someone with a handicap similar to his own, example being proverbially, and otherwise, better than precept.

In the foregoing pages a wide field has been covered in broad outline. Some of the views expressed may not coincide with old and well established customs; on the other hand, they are the result of a long and varied practical experience in dealing with many thousands of cases. It is not suggested that finality has been reached either in surgical technique or mechanical ingenuity, but it is gratifying to find, from comparisons made at first hand with the organisations of the other principal belligerent countries of the Great War, that the types of limbs and appliances provided by the British Ministry of Pensions are the best obtainable in material and workmanship, finish and fit.

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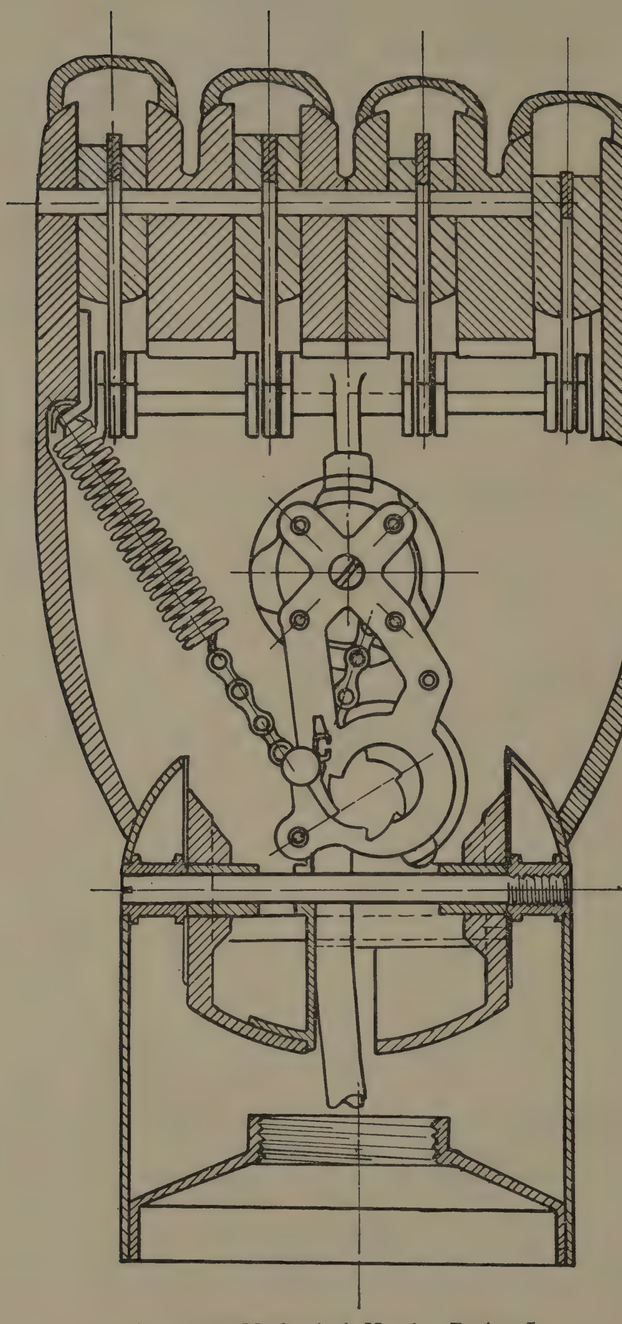

FIG. 32.—Mechanical Hand. Design I.

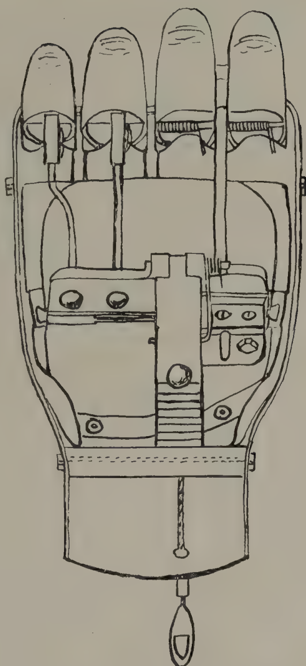

Fig. 33.—Mechanical Hand.
Design II.

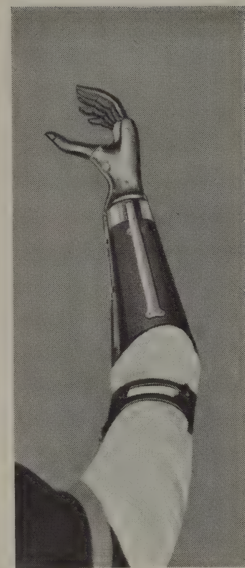

Fig. 33a.

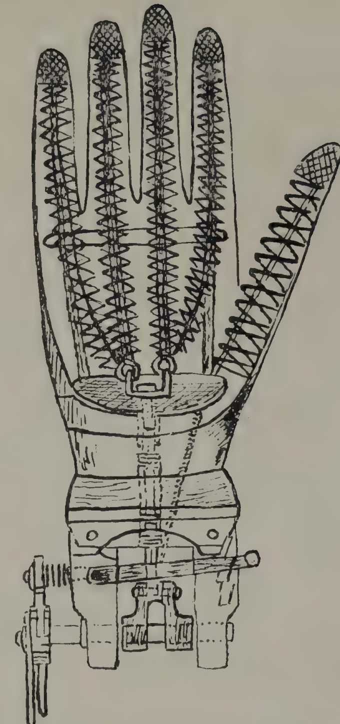

Fig. 34.—Mechanical Hand.
Design III.

Fig. 35.—Plain Hook.

Fig. 36.—Split Hook.

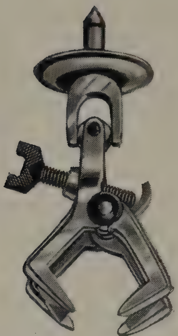

Fig. 37.—Spade Grip.

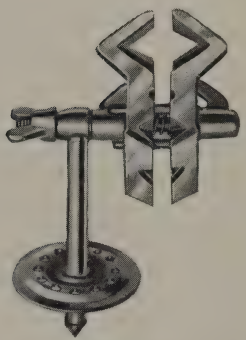

Fig. 38.—Toolholder and Vice.

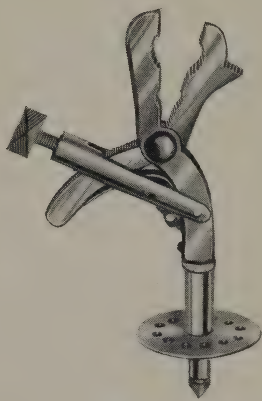

Fig. 39.—Quick Grip Pliers.

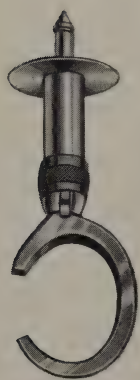

Fig. 40.—
Mechanical " C " Hook.

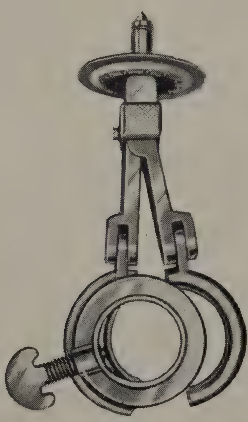

Fig. 41.—
Ring Appliance.

Fig. 42.—
Nail Brush Appliance.